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(IN PREPARATION)

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BUILDING CONSTRUCTION

AND SUPERINTENDENCE.

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Part I.

SEVENTH EDITION

MASONS' WORK.

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PREFACE.

THE primary object of the Author in preparing this volume has been to present to the Student, Architect and Builder a text book and guide to the materials used in Architectural Masonry and the most approved methods of doing the various kinds of work, and incidentally to point out some of the ways in which such work should not be done, and the too frequent methods of slighting the work. That there is a demand for such a work has been evidenced to the Author by numerous inquiries from Architects and instructors in our Architectural schools, and also by the fact that there exists no similiar work describing American methods and materials.

In describing methods of construction the Author has drawn largely from his own observation and experience as a practicing and consulting Architect in both the Eastern and Western States, although much assistance has been obtained from prominent Architects, who have cheerfully aided him by their advice and experience, and from the various books and publications to which references are made in the text; to all such the author gratefully acknowledges his indebtedness.

To make the book convenient for practical use and ready reference, the various subjects have been paragraphed and numbered in bold-face type, and numerous cross references are made throughout the book. The table of contents shows the general scope of the book, the running title assisting in finding the various parts, and a very full index makes everything in the book easy of access. The general character of the work is descriptive, and hence rules and formulæ for strength and stability have, except in a few cases, been omitted; such data being already fully presented in the Author's "Pocket Book" and other similar works.

While intended principally as a book of instruction, there is much in the book that will be found valuable for reference, and of assistance in designing and laying out mason work, preparing the specifications, and in superintending the construction of the building, so that the Author hopes that even the experienced Architect will find it of assistance in his work.

The enterprising builder, also, who wishes to thoroughly understand the materials with which he has to deal, and the way in which they should be used, will find in this book much information that cannot be readily obtained elsewhere.

To make the description as clear as possible many illustrations (mostly from original drawings) have been inserted, and an endeavor has been made to present only practical methods, and to favor only such materials as have been found suitable for the purpose for which they are recommended.

F. E. KIDDER.

Denver, Colo., June 1, 1896.

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ADDITIONS TO SECOND EDITION.

INTRODUCTION.

THE successful practice of Architecture requires not only ability to draw and design, but also a thorough knowledge of building construction in all its branches, at least so far as to know *how* the work should be done, and conscientious and painstaking supervision of the work.

Without a knowledge of the best methods of performing building operations, and of the materials that should be used, it is impossible for the architect to prepare his specifications intelligently, and so as to secure the kind of work he wishes done ; and upon the thoroughness with which the specifications are prepared depends in a great measure the satisfactory execution of the work.

The position occupied by the architect as a judge or referee between the owner and contractor also makes it necessary that he should be able to show such thorough familiarity with common practice as will command the respect of both. Workmen soon discover whether the superintendent is familiar with the difference between good and bad work, and if they find him wanting they are quite sure to take advantage of his lack of knowledge.

After the plans and specifications have been prepared with the utmost care, accidents, failures and bad work are quite sure to occur unless the building operations are carefully and intelligently supervised. In fact, probably more failures in buildings occur from the use of poor materials and bad workmanship than from faults in the plans.

While it is impossible for one to acquire a thorough knowledge of building construction from books alone, it is necessary, for the young architect, especially, to depend upon technical books to a large extent for his knowledge of how work should be done, and of what materials are best suited for certain purposes, and how they should be used. As a substitute for his lack of knowledge, he must rely largely upon knowledge gained through the experience of others, oftentimes at great cost.

In these books the author has endeavored to describe all the ordinary building operations in such a way that they may be easily understood, and to point out the defects often met with in building materials and construction, and to indicate in a measure how they may be avoided.

To get along well with contractors and workmen the architect must feel sure that his opinions and decisions are correct, and *stick to them.* Of course one can often learn much from practical builders, but unless he is already somewhat informed upon the subject he is often likely to be imposed upon. In fact, one of the greatest troubles of young architects in superintending their buildings, lies in

Chapter I.

FOUNDATIONS ON FIRM SOILS.

STAKING OUT THE BUILDING.

1. Except for city blocks, staking out the building is generally left to the contractor, but the superintendent should see that it is carefully done, and very often he is expected or called upon to assist in running the lines. The principal corners of the building should first be carefully located by small stakes driven into the ground with a nail or tack marking the exact intersection of the lines. The lines should then be marked on *batter boards*, put up as shown in Fig. 1. Three large stakes (2x4 or 4x4) are firmly driven or set in the ground at each corner of the building and from six to ten feet from the line of the building, according to the nature of the ground, and fence boards nailed horizontally from the corner post to each of the other two posts. These boards should be long enough so that both the inside and outside lines of the foundation walls may be marked on them. The stakes should also be braced from the bottom of the corner stake to the top of the others. This makes a firm support for the lines and one that need not be moved until the walls are up for the first floor. These boards have the great advantage over single stakes that they are more permanent, and that all projections of the walls, such as footings, basement wall and first story wall, can readily

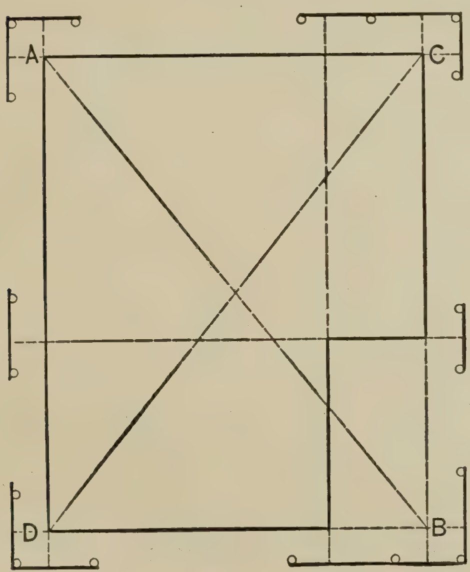

Fig. 1.

be marked on them. It is a good idea to indicate the ashlar line by a saw mark, the basement line by a nail and the footings by a notch, then no mistake can be made by the workmen. If the top of all the horizontal boards are kept on a level it assists a great deal in getting levels for the excavating, etc.

The superintendent will be expected to furnish the contractor with a bench mark, from which he can get the level for his footings, floor joist, etc. This mark should be put on some permanent object, where it can be referred to after the first floor joists are on. In giving such data to the contractor the superintendent must be very careful, as he can be held responsible for any loss resulting from errors which he may make. It is a very safe and good rule to give as few lines, data or measurements as possible to contractors, requiring them to lay out all the work themselves and to be alone responsible for the accuracy of their work.

2. **Diagonals.**—After the batter boards are in place and properly marked, the superintendent should require the contractor or his foreman to stretch the main lines of the building, and the superintendent should carefully measure the diagonals, as A B and C D, Fig 1, with a steel tape ; if they are not exactly of the same length the lines are not at right angles with each other and should be squared until the diagonals are of equal length.

On fairly level ground a building may be accurately laid out by means of a steel tape, using multiples of 3, 4 and 5 for the sides and hypothenuse of a right angle triangle. The larger the triangle the more accurate will be the work.

3. For buildings which are built out to the street line the lines of the lot should be given by a surveyor employed by the owner, and should be fixed by long iron pins driven into the street, or by lines cut on the curbstone across the street. In building close to the party lines of a lot it is, of course, of great importance that the building does not encroach upon the adjacent lot, and to prevent this it is always well to set back one inch from the line, thus allowing for any irregularities or projections in the wall.

FOUNDATIONS—LIGHT BUILDINGS.

4. **Nature of Soils.**—The architect should in all cases make every endeavor to discover the nature of the soil upon which his building is to be built before he makes his foundation plan. For most buildings, a sufficient idea of the nature of the soil may be gained by inquiry amongst builders who have put up buildings on the

adjacent lots. Many soils, however, vary greatly, even in a distance of 100 feet, owing to the strata having a decided dip, and on all such soils much trouble and annoyance may often be saved by having borings made with a post auger, showing the composition of the soil at different strata. If two borings made on different sides of the site show about the same depth and character of soil it may be assumed that other borings would give the same result, but if the soil brought up by the first two borings show a difference in the character of the soil, or indicate that the strata have a decided pitch, then borings should be made all around the foundations.

For ordinary buildings borings to the depth of 8 or 10 feet are generally sufficient, although a 6 or 8-inch auger may be driven to the depth of 20 or 25 feet by two men using a lever. In soft soils a pipe must first be sunk and the auger worked inside of it. A smaller auger will answer in such cases.

For dwellings built on sand, gravel, clay or rock, an examination of the bottom of the trenches, and a few tests with an ordinary crowbar or post auger, will generally be all that is necessary.

When borings are deemed necessary the owner should be advised of the fact, and his authority obtained for incurring the expense, which should be defrayed by him.

5. Different soils have not only different bearing or sustaining powers, but also various peculiarities which must be thoroughly understood and considered when designing the foundation.

An architect who, as a draughtsman, has had several years' experience in one locality before practicing for himself, will naturally have become acquainted with the peculiarities of the soil in that vicinity; but should his practice extend beyond his own city he should carefully study the nature and peculiarities of the soil in each different locality where he may have work, and also obtain all the information possible, bearing on the subject, from local builders, as otherwise he may fall into serious trouble.

No part of a building is more important than the foundation, and more cracks and failures in buildings will be found to result from defective foundations than from any other cause; and for any such defects, resulting from the neglect of usual or necessary precautions, the architect is responsible to the owner, besides the damage which inevitably results to his own reputation.

The following observations are intended as a general guide in preparing foundations on different soils, although they should be supplemented by the experience of local builders wherever possible.

6. Rock.—Rock, when it extends under the entire site of the building, makes one of the best foundation beds, as even the softest rocks will safely carry more weight than is likely to come upon them.

The principal trouble met with in building on rock is the presence of water. As the surface water cannot readily penetrate the rock, it collects on top of the ledge and in the trenches, so that some arrangement for draining away the water should be provided. If the ledge falls off to one side, a tile or stone drain may be built from the lowest point of the footings to near the surface on the slope. If in a sewer district, the water may be drained into the sewer, using proper precautions for trapping and ventilation. If there is no sewer and the rock does not fall off, a pit should be excavated at the lowest part of the cellar to collect the seepage, and an automatic arrangement provided for raising the water into a drain laid above the surface of the rock.

To prepare the rock for the footings, the loose and decayed portions should be cut away and dressed to a level surface. If the surface of the rock dips, or is irregular in its contour, the portion under the footings should be cut to level planes or steps, as shown in Fig. 2. In no case should the footings of a wall rest on an inclined bed.

Fig. 2.

7. If there are fissures or holes in the rock, they should be filled with concrete, well rammed; or, if the fissure be very deep, it may be spanned by an arch of brick or stone. In building on rock it is very desirable that the footings shall be nearly level all around the building, and whenever this is not the case the portions of the foundation which start at the lower level should be laid in cement mortar and with close joints, otherwise the foundations will settle unequally and cause cracks to appear above.

8. Should it be absolutely necessary to build partly on rock and partly on soil, the footings on the soil should be made very wide, so that the settlement will be reduced to a minimum. The footings resting on the rock will not settle, and the least settlement in those resting on the soil will be sure to produce a crack in the superstructure, and perhaps do other damage.

Building on such a foundation bed is very risky at best, and should always be avoided if possible.

9. Clay.—This soil is found in every condition, varying from slate or shale, which will support any load that can come upon it, to a soft, damp material, which will squeeze out in every direction when a moderately heavy pressure is brought upon it.

Ordinary clay soils, however, when they can be kept dry, will carry any usual load without trouble, but as a rule clay soils give more trouble than either sand, gravel or stone.

In the first place, the top of the footings must be carried below the frost line to prevent heaving, and for the same reason the outside face of the wall should be built with a slight batter and perfectly smooth. The frost line varies with different localities, attaining a depth of six feet in some of the very Northern States, although between three and four feet is the usual depth in the so-called Northern States. The effect of freezing and thawing on clay soils is very much greater than on other soils.

The surface of the ground around the building should be graded so that the rain water will run away from the building, and in most clays subsoil drains are necessary. When the clay occurs in inclined layers, great care must be exercised to prevent it from sliding, and when building on a side hill the utmost precautions must be taken to exclude water from the soil, for if the clay becomes wet the pressure of the walls may cause it to ooze from under the footings. The erection of very heavy buildings in such locations must be considered hazardous, even when every precaution is taken.

Should it be necessary to carry a portion of the foundations to a greater depth than the rest, the lower portion of the walls should be built as described in Section 7, and care must be taken to prevent the upper part of the bed from slipping. Wherever possible, the footings should be carried all around the building at the same level.

10. In Eastern Maine, where the soil is a heavy blue clay, and freezes to the depth of four feet, it is customary to build the foundation walls as shown in Fig. 3, the footings being laid dry, to act as a drain, and the bottom of the trench being slightly inclined to one corner, from whence a drain is carried to take away the water. The portion of the trench outside of the wall is also filled with broken stone or gravel to prevent the clay from freezing to the side of the wall. In the better class of work the outside of the wall is plastered smooth with cement. Sometimes a tile drain is laid just outside and a little below the footings.

11. If the clay contains coarse sand or gravel its supporting power is increased, and it is less liable to slide or ooze away.

In Colorado the top soil consists principally of clay, mixed with fine sand, and as long as it is kept dry will sustain a great load without settlement. As soon as the soil becomes wet, however, it turns into a soft mud, which is very compressible and treacherous. For this reason the footings of heavy buildings are carried through the clay to the sand below. A peculiarity of this soil is that, although it freezes, it has never been known to *heave*, so that two-story buildings are often built directly on top of the ground, and as long as water is kept away from the walls no injury results.

12. Gravel.—This material gives less trouble than any other as a foundation bed. It does not settle under any ordinary loads, and will safely carry the heaviest of buildings if the footings are properly proportioned. It is not affected by water, provided it is confined laterally, so that the sand and fine gravel cannot wash out. This soil is also not greatly affected by frost.

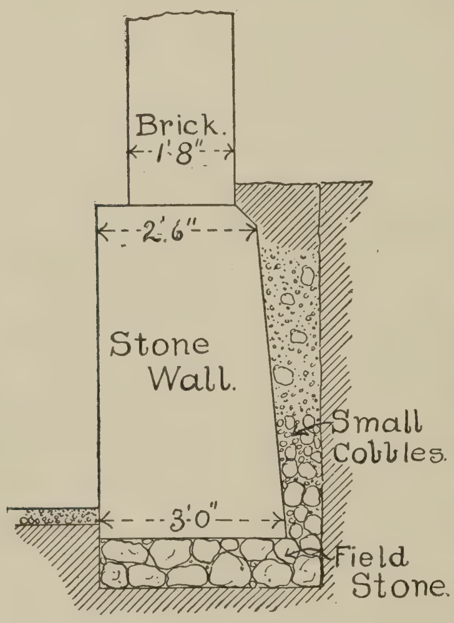

Fig. 3.

13. Sand.—This material also makes an excellent foundation bed when confined laterally, and is practically incompressible, as clean river sand compacted in a trench has been known to support 100 tons to the square foot.

As long as the sand is confined on all sides, and the footings are all on the same level, no trouble whatever will be encountered, unless it be in the caving of the banks in making the excavations. Should the cellar be excavated to different levels, however, sufficient retaining walls must be erected where the depth changes to prevent the sand of the upper level from being forced out from under the footings, and precautions should be taken in such a case to keep water from penetrating under the upper footings.

14. Loam and Made Land.—No foundation should start on loam (soil containing vegetable matter), or on land that has been made or filled in, unless, indeed, the filling consist of clean beach sand, which, when settled with water, may be considered equal to the natural soil.

Loam should always be penetrated to the firm soil beneath, and when the made land or filling overlies a firm earth, the footings should be carried to the natural soil. When the filled land is always wet, as on the coast or the borders of a lake, piles may be used, extending into the firm earth, and the tops cut off below low water mark; but piles should never be used where it is not certain that they will be always wet.

15. Mud and Silt.—Under this heading may be included all marshy or compressible soils which are usually saturated with water.

Foundations on such soils are generally laid in one of the three following ways: 1. By driving piles on which the footings are supported. 2. By spreading the footings either by wooden timbers or steel beams so as to distribute the weight over a large area. 3. By sinking caissons or steel wells, filled with masonry, to hard pan. As all of these methods are more or less complicated they will be described in Chapter II.

16. Bearing Power of Soils.—The best method of determining the load which a particular soil will bear is by direct experiment; but good judgment, aided by a careful examination of the soil—particularly of its compactness and the amount of water it contains—in conjunction with the following table, will enable one to determine with reasonable accuracy its probable supporting power. A mean of the values given below may be considered safe for good examples of the kinds of soils quoted:

TABLE I.—BEARING POWER OF SOILS.

KIND OF MATERIAL.	BEARING POWER IN TONS PER SQUARE FOOT.*	
	MIN.	MAX.
Rock, hard	25	30
Rock, soft	5	10
Clay on thick beds, always dry	4	6
Clay on thick beds, moderately dry	2	4
Clay, soft	1	2
Gravel and coarse sand, well cemented	8	10
Sand, compact and well cemented	4	6
Sand, clean, dry	2	4
Quicksand. alluvial soils, etc.	0.5	1

* Ira O. Baker, C. E., in "Treatise on Masonry Construction."

Should it be desirable to exceed the maximum loads here given, or should there be any doubt of the bearing capacity of the soil or lack of precedent, tests should be made on the bottom of the trenches in several places to determine the actual load required to produce settlement, as described in Section 18.

17. Examples of Actual Loads and Tests.

On Clay.—*The Capitol at Albany, N. Y.*, rests on blue clay containing from 60 to 90 per cent. of alumina, the remainder being fine sand, and containing 40 per cent. of water on an average. The safe load was taken at 2 tons per square foot. A load of 5.9 tons applied on a surface 1 foot square produced an uplift of the surrounding earth.

The Congressional Library at Washington, D. C., rests on yellow clay mixed with sand. It was found that it required about 13½ tons per square foot to produce settlement, and the footings were proportioned for a maximum pressure of 2½ tons

A hard indurated clay, containing lime, under the piers of a bridge across the Ohio River, at Point Pleasant, W. Va., carries approximately 2½ tons per square foot.

Sand.—"In an experiment in France, clean river sand compacted in a trench supported 100 tons per square foot.

"The piers of the Cincinnati suspension bridge are founded on a bed of coarse gravel 12 feet below water; the maximum pressure is 4 tons per square foot.

"The piers of the Brooklyn suspension bridge are founded 44 feet below the bed of the river, upon a layer of sand 2 feet thick, resting upon bed rock; the maximum pressure is about 5½ tons per square foot." *

18. Methods of Testing.—Probably the easiest method of determining the bearing power of the foundation bed is by means of a platform from 3 to 4 feet square, having four legs, each 6 inches square. The platform should be set on the bottom of the trench, which should be carefully leveled to receive the legs. A level should then be taken from a stake or other bench mark not liable to be disturbed to each of the four corners of the platform, and the platform then loaded with dry sand, brick, stone or pig iron, as may be most convenient. The load should be put on gradually, and frequent levels taken until a sinkage is shown. From one-fifth to one-half of the load required to produce settlement is generally adopted for the safe load, according to circumstances. In testing the ground under the Congressional Library a traveling car was used, having four cast iron pedestals, each measuring 1 square foot at the base and set 4 feet apart each way. The car was made to move along the trenches, and halted at intervals in such a way as to bring the whole weight of the car and its load upon the pedestals which rested on the bottom of the trench. In this case the car was loaded with pig lead.

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* Ira O. Baker, C. E. *American Architect*, November 3, 1888.

The only objection to this method is that if the legs do not settle evenly it is impossible to tell just what the pressure on the lowest corner amounts to, but it would not be safe to consider it as more than one-fourth of the whole load.

19. In testing the soil under the State Capitol at Albany, N. Y., the load was placed on a mast 12 inches square, held vertical by guys, with a cross frame to hold the weights. The bottom of the mast was set in a hole 3 feet deep, 18 inches square at the top and 14 inches at the bottom. Small stakes were driven into the ground in lines radiating from the centre of the hole, the tops being brought exactly to the same level, so that any change in the surface of the ground could readily be detected and measured by means of a straight-edge. In this case no change in the surface of the ground was noticed until the load reached 5.9 tons, when an uplift of the surrounding ground was noticed.

DESIGNING THE FOUNDATIONS.

20. Knowing the character and supporting power of the soil on which he is to build, the architect is prepared to design his foundation plans, but in no case should this be done when the preceding information is wanting.

In designing the foundations the first point to be settled will be the depth of the foundations; second, whether they shall be built in piers or in a continuous wall; and, third, the width of the foundations.

21. Depth.—For isolated buildings on firm soil the depth of the foundations will generally be determined by the depth of the basement or by the frost line. Even where there is no frost, and the ground is firm, the footings should be carried at least 2 feet below the surface of the ground, so as to be below the action of the surface water. In very few soils, however, is it safe to start the foundations at a less depth than 5 feet. (See Section 9.)

22. The depth of the foundations for *city buildings*, built near the lot line, should be governed by the local laws bearing on the subject, the character of the soil, and probable future action of the owners of the adjoining property.

In most cities the law provides that the owner of any lot excavating below a certain depth (usually about 10 feet) shall protect the wall of the adjoining property at his own expense, but if he does not excavate below that depth (10 feet) then the adjoining owners must themselves protect their property from falling in.

It is, therefore, always wise to provide against any such future

expense and trouble by carrying the footings—at least those of the side walls—to the prescribed limit, above which the owner will be responsible, even if the requirements of the soil or building do not necessitate it. This precaution is especially important when the building is erected on sand.

23. Continuous Foundations vs. Piers.—It has been found that when heavy buildings are to be erected on soft or compressible soils, greater security from settlement may be obtained by dividing the foundation into isolated piers, as described in Chapter II.

When building on firm soils, however, no advantage is gained by pursuing this method, unless the walls of the building are themselves composed of piers with thin curtain walls between, in which case the foundations under the piers and walls should be built of different widths, and not bonded together, as described in Section 30.

When the walls are continuous, however, and of the same thickness throughout, the foundation should be continuous. The architect should constantly bear in mind that in all kinds of building construction the simplest methods are almost always the best, and complicated arrange . ents and the use of iron, etc , in foundations should be avoided, at least on firm soils.

24. Proportioning the Footings.—Whether the foundations are continuous or divided into piers the area of the footings should be carefully *proportioned to the weight which they support* and the bearing power of the soil. The former is perhaps the most important of all considerations in designing the footings. While the safe bearing power of the soil ought not to be exceeded, this is, on most soils, not of so much importance as the proportioning of the footings, so that the *pressure on the soil from every square foot of the footings will be the same.* If this condition were always obtained there would be few cracks in the mason work of buildings, as such cracks are caused not by a uniform settlement of an inch or two, which with most buildings would not be noticed, but by *unequal* settlement.

25. In proportioning the area of the footings the architect should carefully compute the weights coming upon each pier, and the weight of and loads supported by the walls, and record the same in a memorandum book for reference.

He should then decide, by means of Section 16 and from an examination of the ground, or, if necessary, from actual tests, the bearing weight which it appears advisable to assume, and dividing the load on the various footings by this assumed carrying load will give the proper area of the footings.

The pressure under piers supporting a tier of iron columns may be made 10 per cent. more than under a brick wall, so that the pier may settle a little more to allow for the compression in the joints of the mason work.

26. *In computing the weight* to be supported by the footings the live (or movable) load and dead load should be computed separately. In building on any compact soil the object in carefully proportioning the footings, as has been stated, is not so much to prevent any settling of the building as a whole, but to provide for a uniform settling of all portions of the building, so that the floors may remain level and no cracks be developed in the walls. In order to secure this, it is necessary that the loads for which the footings are proportioned should be as near the actual conditions as possible.* Thus the dead load under the walls of a five-story building would be a considerable item, while the dead load under a tier of iron columns would be much less in proportion to the floor area supported, and, as the dead load is always constant and the live load may vary greatly, only the amount of live load that will *probably* be supported by the footings *most of the time* should be considered.

For warehouses, stores, etc., about 50 per cent. of the live load for which the floor beams are proportioned should be added to the dead load supported on the footings.

For office buildings, hotels, etc., the weight of the people who may occupy them should be neglected altogether in proportioning the footings, and only about 15 pounds per square foot of floor allowed to cover the weight of furniture, safes, books, etc. [Actual statistics show that the permanent average loads in such buildings do not exceed the above limit.]

For theatres and similar buildings some allowance should probably be made for the weight of people, the actual amount depending upon the arrangement of the plan and the character of the soil.

Almost any soil, after it has been compacted by the dead weight of a building, will carry a shifting load of people without further settlement, while if the footings were computed to carry the full live loads for which the floor beams were designed, it would be found that when the building was finished the actual loads on the footings under the walls would be much greater than under the interior piers, and if the ground had settled at all during building, the probabilities

* Foundations shall be proportioned to the actual average loads they will have to carry in the completed and occupied building, and not to theoretical or occasional loads.—*Chicago Building Ordinance.*

would be that the floors of the building would be higher in the centre than at the walls.

27. *Example I.*—We will suppose that a six-story and basement warehouse is to be erected on an ordinary sand and gravel foundation. The building will be 50 feet wide, with two longitudinal rows of columns and girders. What should be the width of the footings under the walls and columns?

Answer.—For the load on one lineal foot of footing under the side walls we will have about 140 cubic feet of brick and stone work, weighing about 17,000 pounds.* One lineal foot of wall will also support about 8 square feet of each floor and the roof. We will assume that the floors are of iron beams and terra cotta tile, with concrete filling, weighing altogether 75 pounds to the square foot, and the roof of the same material, weighing 60 pounds. Then the dead load from the six floors and roof would amount to 4,080 pounds. The first, second and third floors are intended to support 150 pounds to the square foot, and those above 100 pounds per square foot. The possible weight of snow on the roof we will not take into account. There might then be a possible live load on the footing of 6,000 pounds, but as it is improbable that each floor will be entirely loaded at the same time, and as some space must be reserved for passages, etc., the actual live load would probably not exceed for any length of time 50 per cent. of the assumed load, or 3,000 pounds. Adding these three loads together (the wall, floors and live load) we have 24,080 pounds as the load on one lineal foot of footing. We will allow 6,000 pounds (3 tons) for the bearing power of the soil, and dividing the load by 6,000 we have 4 feet as the required width of the footing. The load on the footings under the columns will consist only of the weight of the floors and the roof and the live load, plus the weight of the tier of columns, which would be so small in proportion to the other loads that it need not be considered. If the columns were 14 feet apart longitudinally, each column would support 224 square feet of each floor, so that the total dead load on the footing under the columns will amount to 114,240 pounds, and the possible live load to 168,000 pounds. As it would be scarcely possible for every foot of floor on every floor being loaded to its full capacity at the same time, we would probably come nearer the actual conditions if we take only 50 per cent. of the total live load, or 84,000 pounds, making a total load on the footing of 198,240 pounds, which

* For weight per cubic feet of materials, see table in appendix.

would require 33 square feet in the area of the footing. But as there will be no shrinkage or compression in the iron columns we had better reduce this area 10 per cent., making 30 square feet, or 5½ feet square.

The above calculations should be entered in a memorandum book, kept for the purpose, somewhat as follows:

DATA FOR FOOTINGS.

	UNDER ONE FT. OF SIDE WALLS.	UNDER COLUMNS.
Cubic feet of brickwork, 108 @ 120 =	12,960 lbs.	
Cubic feet of stonework, 28 @ 150 =	4,200	
Total weight of wall	17,160 lbs.	Nothing
Floor area supported	8 □′	16 × 14 = 224 □′
Weight of floors per □′ 75 lbs.		
Weight of roof per □′ 60 lbs.		
Total for six floors and roof: 510 × 8 =	4,080	510 × 224 = 114,240
Live load per □′—		
1st, 2d and 3d floors, 150 lbs.		
3d, 4th and 5th floors, 100 lbs.		
Total live load, 8 × 750 =	6,000	750 × 224 = 168,000
50% of this =	3,000	84,000
Total load	24,240	198,240

Assumed bearing load, 6,000 lbs.
Width of footings under wall, 4 ft.; under columns, 33 □′ less 10%, or 5′ 6″ × 5′ 6″.

The front and rear walls, if continuous, would not have to support any floor loads, and the footings should be reduced in proportion. The footings under the piers supporting the ends of the girders should also be separately computed.

28. In the case of light buildings it will often be found that the computed width of footings will be less than that required by the building ordinance, in which case it will of course be necessary to comply with the ordinances or building laws. As a rule, the footings under a foundation wall should be at least 12 inches wider than the thickness of the wall to give it stability. Even in light buildings the footings under the different portions of the buildings should be carefully proportioned, so that all will bring the same pressure per square foot on the ground. In cases where the width of the footing is regulated by the building law, the pressure per square foot under the footing should be computed, and the footings under all piers, etc., proportioned to this standard. In cases where a high tower adjoins a lower wall the footings under the two portions must be carefully proportioned to the weight on each, otherwise the wall may crack where it is bonded into the tower.

Example II.—To illustrate the manner in which the width of the footings should be proportioned when the pressure under the footings

is very light, we will take the case of a one-story stone church, having side walls 20 inches thick and 22 feet high above the footings, and a tower at the corner 60 feet high, the first 22 feet being 24 inches thick and the balance 20 inches thick. The roof is supposed to be supported by trusses and purlins, so that only the lower 6 feet of the roof rests on the side walls. The side walls also carry 6 feet of the floor; the tower has a flat roof 12 feet square.

The computations for the weights on the soil under the side walls and under the tower wall would be as follows:

UNDER SIDE WALLS.	
Stonework, 22′ x 20″ = $36\frac{2}{3}$ cu.ft. at 150 lbs. per cu.ft.,	5,500 lbs.
Weight of first floor, 130 lbs. x 6 □′ =	780 "
Weight of roof below purlin, 40 lbs. x 6 □′ =	240 "
Total weight on soil......	6,520 "

UNDER TOWER WALL.	
Stonework, 22′ x 24″ = ...	44 cu. ft.
38′ x 22″ = ...	$63\frac{1}{3}$ "
$107\frac{1}{3}$ x 150 = ...	16,100 lbs.
Weight of floor, 130 x 6 = ..	780 "
Weight of roof, 40 x 6 = ..	240 "
Total weight on soil.....	17,120 "

Width of footings, 3 ft.
Pressure per □′ under footings, 2,173 lbs.
Width of footings under tower, 17,120 ÷ 2,173 = 7.8 ft.

In this case the width of the footings under the side wall should be determined by the question of stability, and should not be less than 3 feet. Then if the pressure under the tower were reduced to the same unit per square foot, the tower footings would need to be nearly 8 feet wide. On firm soils, however, such as sand, gravel, or compact clay, it would not be necessary to make the footings so wide as this, as the soil would probably not settle appreciably under a considerably greater pressure, so that if the footings of the tower were made 6 feet wide, there would probably be no danger of unequal settlement. Of course the greater the unit pressure on the soil the more exact must be the proportioning of the footings.

29. Centre of Pressure to Coincide with Centre of Base.—That the walls and piers of a building may settle uniformly without producing cracks in the superstructure, it is not only essential that the area of the footings shall be in proportion to the load and the bearing power of the soil, but also that the *centre of pressure* (a vertical line through the centre of gravity of the weight) *shall pass through the centre of the area of the foundation.*

This condition is of the first importance, for if the centre of pressure does not coincide with the centre of the base, the ground will yield most on the side which is pressed most, and as the ground yields the base assumes an inclined position and carries the lower

part of the structure with it, thus producing unsightly cracks, if nothing more.

A case in which a violation of this rule cannot well be avoided is the foundation under the side wall of a building, where the footing is not allowed to project beyond the lot line. In such a case the centre of pressure is indicated by the downward arrow, and the centre of base by the upward arrow, Fig. 4. It is evident that the intensity of the pressure is greatest on the portion of the footing to the right of the centre of base, and the footing will in consequence settle obliquely as shown in the figure, having a tendency to throw the wall outward. This tendency may be counteracted by tying the wall securely to the floor joist, but it would be much better if some arrangement could be made so that the footing would settle evenly. Where

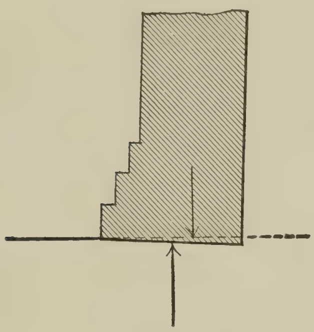

Fig. 4.

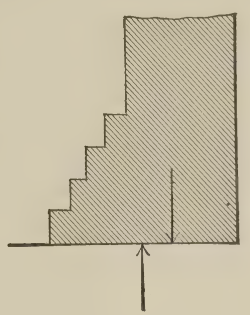

Fig. 5.

it is absolutely necessary to build the footing without projecting beyond the lot line, the footing should be carefully built of dimension stone, or of hard brick, well grouted in cement mortar, and the footing should be no wider than is absolutely demanded by the nature of the soil, and the offsets on the inside of the wall should be very slight. The footing shown in Fig. 4 is to be preferred to that shown in Fig. 5.

30. Fig. 6 illustrates another case where the centre of pressure comes outside the centre of base, consequently the wall inclines outward, producing cracks over the opening. This is a very common occurrence in brick and stone walls where wide openings occur. In such cases the footing under the opening should either be omitted entirely or made much narrower than under the pier, and the two should not be bonded together. Where several openings occur one

above the other, as in Fig. 7, and the footing is continued under the opening, the unequal settlement of the footings will very likely produce cracks over all the openings, the side walls inclining slightly outward. Where the width of the opening is 8 feet or more, and the bottom of the opening is not a great ways above the footing, the footing under the wall on each side should be treated as under a pier, as shown in Fig. 8, and the space between the footings filled in with a dwarf wall only. If the bottom of the opening is twice its width above the foundation, the wall under the opening will distribute the weight equally over the footing and the settlement will be uniform.

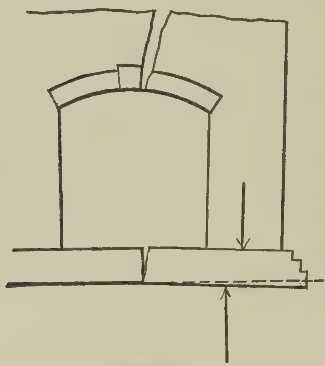

Fig. 6.

As a rule the foundation of a wall should never be bonded into that of another wall either much heavier or much lighter than itself.

The footings should also be proportioned so that the centre of pressure will strike a little *inside* of the centre of the base, to make

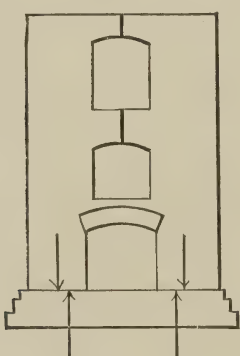

Fig. 7.

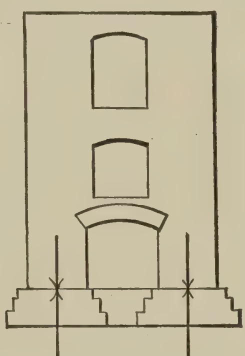

Fig. 8.

sure that it will not be *outside*. Any inward inclination of the wall is rendered impossible by the interior walls and the floors, while an outward inclination can be conteracted only by anchors and the bond of the masonry. A slight deviation of the centre of the pressure outside of the centre of the base has a marked effect, and is not easily counteracted by anchors.

At Chicago an omission of 1 to 2 per cent. of the weight (by leaving openings) usually causes sufficient inequality in the settlement to produce unsightly cracks.*

Where slight differences in weight occur, cracks may generally be prevented by building in hoop iron ties, rods or beams over the openings. It is also a wise precaution, where one wall joins another, either in the middle or at the corner of a building, to tie the walls together by long iron anchors built into the walls about every six feet in height.

SUPERINTENDENCE.

31. In inspecting the excavation the superintendent should first examine the lines to see that the building has been correctly staked out, and that the excavation is being carried at least 6 inches outside of the wall lines, so as to give room for pointing or cementing. If the wall is built against the bank it will be impossible to point up the joints on the outside, and the back of the wall not being exposed, the masons are apt to slight that part of the work to the future detriment of the building; and if the excavation is not made large enough at first, it causes much trouble and vexation, as the work cannot be done as cheaply afterward, and the stone masons will very likely complain about being delayed.

The superintendent should also see that the finished grade is plainly marked on some fixed object and caution the workmen not to dig the trenches below the level marked on the drawings. If the trenches are excavated below the proper level, they must not be refilled with earth, as the footings should start on the solid bottom of the trench; as this will require more masonry than the contractor estimated on, he will be quite sure to call for an extra payment for the same from the owner, unless the excavating is included in his contract, in which case he will have to settle with the excavator. For this reason it is a good plan to have the excavating included in the contract for the foundation.

The superintendent should also examine the character of the soil at the bottom of the excavation, and if it is not such as was expected, the foundations must be changed or carried deeper, as previously described. Should water be encountered in making the excavation some provision should be made for draining the cellar, either by laying a tile drain around the footings, or by laying the bottom courses dry and connecting with a stone drain, as described in Sections 6 and 10.

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* Prof. Ira O. Baker, C. E., in "Masonry Construction."

The specifications should provide that the contractor is to keep the trenches free from water while the wall is being laid. In places where the water cannot be drained off, it must be removed by a pump, either worked by hand or by steam. When the excavation is made close to an adjoining building the superintendent should see that the contractor has made proper provision for shoring or otherwise protecting the adjacent walls.

Chapter II

FOUNDATIONS ON COMPRESSIBLE SOILS.

32. The soils of this class that are met with in preparing the foundations of buildings are generally along the shore of some large body of water, and hence generally permeated with water to within a few feet of the surface.

For such soils pile foundations are usually the cheapest and most reliable. On a soil such as underlies Chicago, and having a supporting power of from 1½ to 2½ tons per square foot, spread foundations may be used with satisfactory results and with economy, when it would require piles over 40 feet long to reach hard pan.

Occasionally it is necessary to build on ground that has been filled in to a considerable depth, and in which water is not present, or the building may be so heavy that it is impracticable to support it on piles: in such cases wells of solid masonry, with an iron casing, or pneumatic caissons, should be sunk to bed rock or hard pan, as hereinafter described.

PILE FOUNDATIONS.

When it is required to build on a compressible soil that is *constantly saturated* with water and of considerable depth, the cheapest and generally the best foundation bed is obtained by driving piles.

33. **Classes of Piles.**—A great many kinds of piles are used in engineering works, but for the foundations of buildings it is very seldom, if ever, that any other than wooden piles are used.

The different conditions under which piles are used for supporting buildings may be classed as follows:

1. When the compressible soil is not more than 40 feet deep and overlays a bed of rock, gravel, sand, or clay, long piles should be driven to the rock, or one or two feet into the clay or sand, in which case they may be considered as columns.

2. If the soft soil is more than 40 feet deep piles varying from 15 to 40 feet in length should be driven, according to the character of the soil, the sustaining power of the piles depending upon the friction between the pile and the surrounding soil.

3. Short piles, 10 to 15 feet long, are sometimes driven, particularly in Southern cities, to consolidate the soil and give it greater resisting power. As piles are seldom used in this way, this method of forming a foundation bed will be dismissed with the following quotation:

34.—

"In some sections of the country, especially in the Southern cities, the soil is of a soft alluvial material, and in its natural state is not capable of bearing heavy loads. In such cases trenches are dug as in firm material, and a single or double row of short piles are driven close together, and under towers or other unusually heavy portions of the structure the area thus covered is filled with these piles. The effect of this is to compress and compact the soil between the piles, and to a certain extent around and on the outside, thereby increasing its bearing power; whatever resistance the piles may offer to further settlement may be added, though not relied upon. These piles are then cut off close to the bottom of the trench, and generally a plank flooring is laid resting on the soil and piles, or a layer of sand or concrete is spread over the bottom of the trench to the depth of 6 inches or 1 foot, and the structure, whether of brick or stone, commenced on this. There is little or no danger of such structures settling, and if they do the chances are that they will settle uniformly if the number of piles are properly proportioned to the weight directly above them; but if the piles are not so proportioned, the same number being driven under a low wall as under a high wall, unequal settlement is liable to take place, causing ugly or dangerous cracks in the structure."*

4. Sheet piles, consisting of two or three-inch plank driven close together, edge to edge, are often used to sustain a bank during excavation, but are seldom depended upon for permanent effect.

35. **Material.**—Piles are made from the trunks of trees, and should be as straight as possible, and not less than 5 inches in diameter for light buildings or 8 inches for heavy buildings. The woods generally used for piles in the Northern States are the spruce, hemlock, white pine, Norway pine, Georgia pine, and occasionally oak. In the Southern States Georgia or pitch pine, cypress and oak are used. Oak is considered as the most durable wood for piles, and is also the toughest, but it is too expensive for general use in the Northern States, besides being difficult to obtain in long, straight pieces. Next to oak come Georgia pine, Oregon pine, cypress and spruce, in the order named.

Of the 1,700 piles supporting the new Illinois Central Railway Station in Chicago, 32 per cent. were black gum, 22 per cent. pine, 7 per cent. basswood, 21 per cent. oak, 15 per cent. hickory, with a few maple and elm. A less proportion of the hickory piles were broken or crushed than of any other wood.

36. **Pointing and Ringing.**—Piles should be prepared for driving by cutting off all limbs close to the trunk and removing the bark.

* "A Practical Treatise on Foundations." W. M. Patton, C. E.

The small end should be sharpened to a point 2 inches square, the bevel being from 18 to 24 inches long. The large end should be cut square to receive the blows from the hammer.

Experience has shown that in soft and silty soils the piles can be driven in better line without pointing. A pointed pile, on striking a root or similar obstruction, will inevitably glance off, and no available power can prevent it; while a blunt pile will cut or break the obstruction without being diverted from its position.

Piles that are to be driven in, or exposed to, salt water should be thoroughly impregnated with creosote, dead oil of coal tar, or some mineral poison to protect them from the "teredo" or ship worm, which will completely honeycomb an ordinary pile in three or four years.

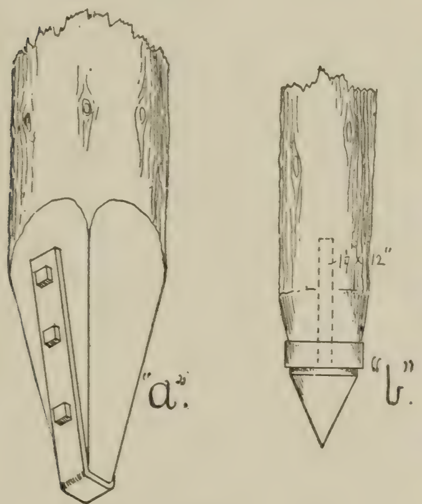

Fig. 9.

Ringing.—When the penetration at each blow is less than 6 inches, the top of the pile should be protected from "brooming" by putting on an iron ring about 1 inch less in diameter than the head of the pile, and from 2½ to 3 inches wide by ⅝ inches thick. It is better to chamfer the head so the ring will just fit on than to drive the ring into the wood by the hammer, as the latter method is liable to split long pieces from the pile.

When driving into compact soil, such as sand, gravel or stiff clay. the point of the pile is often shod with iron, either in the form of straps bolted to the end of the pile, as at *a*, Fig. 9, or by a conical cast steel shoe about 5 inches in diameter and having a 1¼-inch dowel 12 inches long fitting into a hole in the end of the pile and a ring put around the pile, as shown at *b*, to prevent it from splitting. The latter method should be used in very hard soils. If straps are used, as at *a*, they should be 2½ inches wide, ½ inch thick and 4 feet long.

37. Manner of Driving.—The usual method of driving piles is by a succession of blows given with a block of cast iron called the

hammer, which works up and down between the uprights of a frame or machine called a pile-driver. The machine is placed over the pile, so that the hammer descends fairly on its head, the piles always being driven with the small end down. The hammer is generally raised by steam power, and is dropped either automatically or by hand. The usual weight of the hammers used for driving piles for building foundations is from 1,200 to 1,500 pounds, and the fall varies from 5 to 20 feet, the last blows being given with a short fall.

In driving piles care should be taken to keep them plumb, and when the penetration becomes small the fall should be reduced to about 5 feet, the blows being given in rapid succession.

Whenever a pile refuses to sink under several blows, before reaching the average depth, it should be cut off and another pile driven beside it.

When several piles have been driven to a depth of 20 feet or more and refuse to sink more than ½ inch under five blows of a 1,200 pound hammer falling 15 feet, it is useless to try them further, as the additional blows only result in brooming and crushing the head and point of the pile, and splitting and crushing the intermediate portions to an unknown extent.

"Sometimes piles drive easily and regularly to a certain depth, and then refuse to penetrate farther; this may be caused by a thin stratum of some hard material, such as cemented gravel and sand or a compact marl. It may require many hard and heavy blows to drive through this, thereby injuring the piles, and perhaps getting into a quicksand or other soft material, when the pile will drive easily again. If the depth of the overlying soil penetrated is sufficient to give lateral stability, or if this can be secured by artificial means, such as throwing in broken stone or gravel, it would seem unwise to endeavor to penetrate the hard stratum, and the driving should be stopped after a practical refusal to go with two or three blows. The thickness of this stratum and nature of the underlying material should be either determined by boring or by driving a test pile, to destruction if necessary. In the latter case the driving of the remaining piles should cease as soon as the hard stratum is reached." *

If the hard stratum, however, is only 2 or 3 feet thick, with hard pan not more than 40 or 50 feet from the surface, the piles should be driven to hard pan for heavy buildings; but if the soft material continues for an indefinite depth below the hard stratum, the piles should be stopped when the stratum is reached. In such

* "A Practical Treatise on Foundations." W. M. Patton, C. E.

cases, however, the actual bearing power of the piles should be tested by loading one or more of the piles, as described in Section 40.

38. Bearing Power of Piles.—When driven in sand or gravel, or to hard pan, piles will carry to the full extent of the crushing strength of the timber, providing the depth of the pile is sufficient to secure lateral stiffness.

"There are examples of piles driven in stiff clay to the depth of 20 feet that carry from 70 to 80 tons per pile: there are many instances in which piles carry from 20 to 40 tons under the above conditions. After a pile has been driven to 20 feet in sand or gravel, any further hammering on the piles is a waste of time and money, and injurious to the pile itself." *

Piles driven from 30 to 40 feet in even the softest alluvial soils should carry by frictional resistance alone from 10 to 12½ tons.

For the safe working loads on piles driven in different soils, the following table, compiled from the *Engineering News* formula, may be used with safety. The values are for minimum lengths of spruce piles and average penetration for last five blows of a 1,200 pound hammer falling 15 feet. When heavier loads than these must be carried, or the penetration is much greater, the actual bearing power of the piles should be determined by testing, unless it is already known from actual experience.

TABLE II.—BEARING VALUE OF PILES.

SOIL.	PILE LENGTHS.	AVERAGE DIAMETER	PENETRATION.	LOAD IN TONS.
	Ft.	Ins.	Ins.	
Silt	40	10	6	2¼
Mud	30	8	2	6
Soft earth with boulders or logs	30	8	1½	7
Moderately firm earth or clay with boulders or logs	30	8	1	9
Soft earth or clay	30	10	1	9
Quicksand	30	8	½	12
Firm earth	30	8	½	12
Firm earth into sand or gravel	20	8	¼	14
Firm earth to rock	20	8	0	20
Sand	20	8	0	20
Gravel	15	8	0	20

When the penetration is less than that given above, for soft soils the safe loads may be increased according to the *Engineering News* formula given in the next paragraph.

* "A Practical Treatise on Foundations."

There have been several formulæ proposed for determining the safe working loads on piles. Of these, the latest, known as the *Engineering News* formula, is generally considered to be the most reliable. It is claimed for this formula that it sets "a definite limit, high enough for all ordinary economic requirements, up to which there is no record of pile failures, excepting one or two dubious cases where a hidden stratum of bad material lay beneath the pile, and above which there are instances of both excess and failure, with an increasing proportion of failures as the limit is exceeded."

The formula is :

$$\text{Safe load in lbs.} = \frac{2\,w\,h}{s+1}$$

in which w = weight of hammer in pounds; h, its fall in feet; s, average set under last blows in inches.

39. Municipal Regulations.—The New York Building Law (1892) provides that

"Piles intended for a wall, pier or post to rest upon shall not be less than 5 inches in diameter at the smallest end, and shall be spaced not more than 30 inches on centres, or nearer, if required by the Superintendent of Buildings, and they shall be driven to a solid bearing.

"No pile shall be weighted with a load exceeding 40,000 pounds.

"The tops of all piles shall be cut off below the lowest water line. When required, concrete shall be rammed down in the interspaces between the heads of the piles to a depth and thickness of not less than 12 inches and for 1 foot in width outside of the piles."

The Boston Building Law requires that

"Where the nature of the ground requires it all buildings shall be supported on foundation piles not more than 3 feet apart on centres in the direction of the wall. . . . . Buildings over 70 feet in height shall rest, where the nature of the ground permits, upon at least three rows of piles, or an equivalent number of piles arranged in less than three rows. All piles shall be capped with block granite levelers, each leveler having a firm bearing on the pile or piles it covers."

In Chicago it is required that

"The piles shall be made long enough to reach hard clay or rock, and they shall be driven down to reach the same, and such piles shall not be loaded more than 25 tons to each pile."

General William Sooy Smith, in an address delivered March 31, 1892, before the students of engineering of the University of Illinois, stated that "A pile at the bottom of a pit 30 feet deep and well into hard pan, or to the rock where this is within reach, can be safely relied upon to sustain from 30 to 40 gross tons."

40. Experiments on the Bearing Power of Piles.—The following description of several tests made to determine the actual

sustaining power of piles in various localities gives a good idea of the manner of making such tests, as well as the loads which it required to sink them :

Chicago Public Library.—To determine the actual resistance of the piles on which it was proposed to erect the Public Library building in Chicago, the following test was made: In order to make the experiment under the same conditions as would exist under the structure three rows of piles were driven into the trench, the piles in the middle row being then cut off below the level at which those in the outside row were cut off, so as to bring the bearing only on four piles, two in each outside row. This gave the benefit arising from the consolidation of the material by the other piles. The piles were of Norway pine, 54 feet long, and were driven about $52\frac{1}{2}$ feet—about 27 feet in soft, plastic clay, 23 feet in tough, compact clay, and 2 feet in hard pan. They had an average diameter of 13 inches and area at small end of 80 square inches.

On top of the four outside piles, which were spaced 5 feet apart on centres, 15-inch steel I-beams were placed, and upon these a platform, 7x7 feet, composed of 12x12-inch yellow pine timbers. On this platform pig iron was piled up at irregular intervals. When 4 feet high the load was 45,200 pounds, and was then continued, until at the end of about four days it was 21 feet high, giving a load of 224,500 pounds. Levels were taken, but no settlement had occurred. By the end of about eleven days the pile of iron had reached the height of 38 feet, giving a load of 404,800 pounds upon the four piles, or about 50.7 tons per pile. Levels were then taken at intervals during a period of about two weeks, and, no settlement having been observed, a load of 30 tons was considered perfectly safe.

Perth Amboy, 1873.—Pretty fair mud, 30 feet deep. Four piles, 12, 14, 15 and 18 inches diameter at top, 6 to 8 inches at foot, were driven in a square to depths of from 33 to 35 feet. A platform was built upon the heads of the piles and loaded with 179,200 pounds, say 44,800 pounds per pile. After a few days the loads were removed. The 18 inch pile had not moved, the 12-inch pile had settled 3 inches, and the 14 and 15-inch piles had settled to a less extent.*

Buffalo, N. Y.—In the construction of a foundation for an elevator at Buffalo, N. Y., a pile 15 inches in diameter at the large end, driven 18 feet, bore 25 tons for twenty-seven hours without any ascertainable effect. The weight was then gradually increased until the total load on the pile was $37\frac{1}{2}$ tons. Up to this weight there had been no depression of the pile, but with $37\frac{1}{2}$ tons there was a gradual depression which aggregated $\frac{5}{8}$ of an inch, beyond which there was no depression until the weight was increased to 50 tons. With 50 tons there was a further depression of $\frac{7}{8}$ of an inch, making the total depression $1\frac{1}{2}$ inches. Then the load was increased to 75 tons, under which the total depression reached $3\frac{1}{6}$ inches. The experiment was not carried beyond this point. The soil, in order from the top, was as follows : 2 feet of blue clay, 3 feet of gravel, 5 feet of stiff red clay, 2 feet of quicksand, 3 feet of red clay, 2 feet of gravel and sand and 3 feet of very stiff blue clay. All the time during this experiment there were three pile-drivers at work on the foundation, thus keeping up a tremor in the ground. The water from Lake Erie had free access to the pile through the gravel.†

*"A Practical Treatise on Foundations."

†"Masonry Construction." Baker.

"Subsequent use shows that 74,000 pounds is a safe load."—*Patton.*

Philadelphia.—At Philadelphia in 1873 a pile was driven 15 feet into soft river mud, and five hours after 7.3 tons caused a sinking of a very small fraction of an inch; under 9 tons it sank $\frac{3}{4}$ of an inch, and under 15 tons it sank 5 feet.

"The South Street bridge approach, Philadelphia, fell by the sinking of the foundation piles under a load of 24 tons each. They were driven to an absolute stoppage by a 1-ton hammer falling 32 feet. Their length was from 24 to 41 feet. The piles were driven through mud, then tough clay, and into hard gravel."*

The failure in this case may have been caused by vibrations which allowed the water to work its way down the sides of the piles and thus decrease the friction; or, what is more probable, the last blow was struck on a broomed head, which would greatly reduce the penetration and cause the bearing power to be overestimated.

When the penetration is very slight or unobservable, and the head much broomed, the broomed portion should be cut off and the blows repeated if the full load of the formula is to be put on the piles.

41. Actual Loads on Piles.—The following examples of the actual loads which are carried by each pile under the buildings named will serve as a guide to architects erecting buildings in those localities:

Boston.—Under Trinity Church, 2 tons each.

Chicago.—New Public Library building, 30 tons.

Schiller Building, estimated load 55 tons per pile; building settled from $1\frac{1}{2}$ to $2\frac{1}{4}$ inches.

Passenger Station, Northern Pacific Railroad, Harrison Street: piles 50 feet long carry 25 tons each without perceptible settlement.

The enormous grain elevators in Chicago rest upon pile foundations. Mr. Adler states that the unequal and constantly shifting loads are a severer test upon the foundations than a static load of a twenty-story building.

New Orleans.—Piles driven from 25 to 40 feet in a soft, alluvial soil carry safely from 15 to 25 tons, with a factor of safety of 6 to 8.—*Patton.*

42. Spacing.—Piles should not be spaced less than 2 feet on centres, nor more than 3 feet, unless iron or wooden grillage is used.

When long piles are driven nearer than 2 feet from centres there is danger that they may force each other up from their solid bed on the bearing stratum. Driving the piles close together also breaks up the ground and diminishes the bearing power.

When three rows of piles are used the most satisfactory spacing is 2 feet 6 inches from centres across the trench and 3 feet from centres longitudinally, provided this number of piles will carry the weight of the building. If they will not, then the piles must be spaced closer together longitudinally, or another row of piles driven, but in no case drive two piles less than 2 feet apart from centres.

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* Trans. Am. Soc. of C. E., Vol. VII., p. 264.

In all cases, wherever buildings are supported, the number of piles under the different portions of the building should be carefully proportioned to the weight which they have to carry, so that every pile will support very nearly the same load. This precaution is of especial importance when part of the piles must be loaded to their full capacity.

43. Cutting Off and Capping.—The tops of the piles should invariably be cut off below low water mark, otherwise they would soon commence to decay.

The cutting off of the piles in building foundations is generally done by means of a large cross-cut saw worked by two men. The tops of the piles should be left true and level and on a line with each other. A variation of $\frac{1}{2}$ an inch in the top of the piles may be allowed, but it should not exceed this limit.

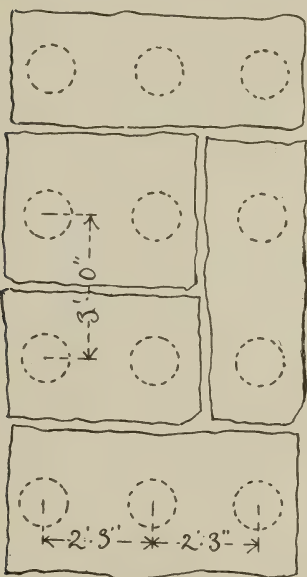


Fig. 10.

Three methods of capping piles are commonly employed: 1. By granite blocks. 2. By concrete. 3. By timber grillage.

44. Granite Capping.—In Boston it is obligatory to cap the piles with blocks of granite, which rest directly on the tops of the piles. If the stone does not fit the surface of the pile, or a pile is a little low, it is wedged up with oak or stone wedges. In capping with stone a section of the foundation should be laid out on the drawings showing the arrangement of the capping stones.

A single stone may rest on one, two or three piles, but *not* on four, as it is practically impossible to make the stone bear evenly on four piles. Fig. 10 shows the best arrangement of the capping for three rows of piles. Under dwellings and light buildings the piles are often spaced as in Fig. 11, in which case each stone should rest on three piles. After the piles are capped large footing stones, extending in one piece across the wall, should be laid in cement mortar, as shown in Fig. 12.

45. Concrete Capping.—In New York a very common method of capping the piles is to excavate to a depth of 1 foot below the top

of the piles and 1 foot outside of them, and fill the space thus excavated solid with rich Portland cement concrete, deposited in layers and well rammed. After the concrete is brought level with the top of the piles additional layers are laid over the whole foundation until it reaches a depth of 18 inches above the piles. On this foundation bed, the brick or stone footings are laid as on solid earth. Many engineers consider this the best method of capping. There is certainly no question of its durability, and it is believed that the concrete will preserve the heads of the piles from rotting, provided the water is at all times up to the bottom of the concrete. A concrete beam 18 inches thick would also serve to distribute the pressure over

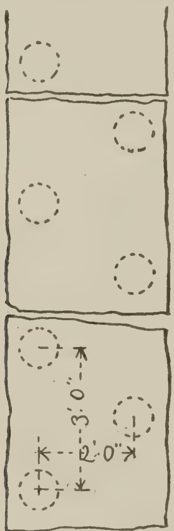


Fig. 11.

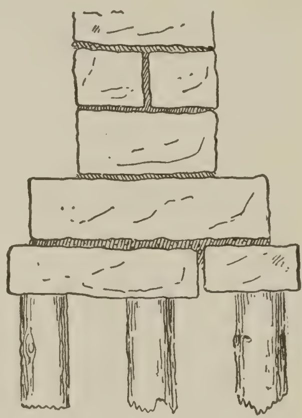


Fig. 12.

the piles better than the stone capping, although not to such an extent as heavy grillage.* If the soil is at all firm under the concrete, it will also assist the piles in carrying the load when concrete capping is used. Under very heavy buildings the space between the piles to the depth of 1 foot should be filled with concrete, whatever kind of capping is employed.

46. Grillage.—In Chicago most of the buildings having pile foundations have heavy timber grillage bolted to the tops of the piles, and on these timbers are laid the stone or concrete footings. For building foundations the grillage usually consists of 12x12 timbers of the strongest woods available, laid longitudinally on top of the piles, and

* By inserting twisted iron bars in the top and bottom of the concrete it may also be given great transverse strength.

strongest woods available, laid longitudinally on top of the piles, and fastened to them by means of *drift bolts*, which are plain bars of iron, either round or square, driven into a hole about 20 per cent. smaller than the iron. One-inch round or square bars are generally used, the hole being bored by a $\frac{3}{4}$-inch auger for the round bolts or a $\frac{7}{8}$-inch auger for the square bolts. The bolts should enter the pile at least 1 foot.

If heavy stone or concrete footings are used, and the space between the piles and timbers is filled with concrete level with the top of the timbers, no more timbering is required; but if the footings are to be made of small stones, and no concrete is used, a solid floor of cross timbers, at least 6 inches thick, for heavy buildings should be laid on top of the longitudinal capping and drift-bolted to them.

Where timber grillage is used it should, of course, be kept entirely below the lowest recorded water line, otherwise it will rot and allow the building to settle. It has been proved conclusively, however, that any kind of sound timber will last practically forever if completely immersed in water.

The advantages of timber grillage are that the timbers are easily laid and effectually hold the tops of the piles in place. They also tend to distribute the pressure evenly over the piles, as the transverse strength of the timber will help to carry the load over a single pile, which for some reason may not have the same bearing capacity as the others.

Steel beams, imbedded in concrete, are sometimes used to distribute the weight over piles, but some other form of construction can generally be employed at less expense and with equally good results.

Objections to Pile Foundations.—It has been claimed that driving piles in a soil such as that under Chicago, within a few feet of buildings having spread foundations, has a tendency to cause the latter to settle so as to necessitate underpinning.

On driving the first piles for the Schiller Building it was found that an adjoining building had settled 6 inches, and it had to be raised on screws.

The driving of piles also causes a readjustment of the particles of clay and sand into a jelly, thus destroying the resisting qualities. These objections, however, are not of so much moment when the adjoining buildings are supported by piles.

SPREAD FOUNDATIONS.

Compressible soils are often met with which will bear from 1 to 2 tons per square foot with very little settlement, and, as a rule, this settlement is uniform under the same unit pressure (pressure per square foot). In such cases it is often cheaper to spread the foundations so

as to reduce the unit pressure to the capacity of the soil than to attempt to drive piles. "Spread" footings may be built of concrete with iron tension bars, of steel beams and concrete, or of timber and concrete.

48. Concrete with Iron Tension Bars.—When the necessary height can be obtained, spread footings composed of Portland cement concrete, with iron tension members, have more qualities to recommend them than any other construction. Such footings are easy of construction, they are cheap, and their durability is everlasting. The iron being so completely imbedded in the concrete it cannot rust,* and hence there is no possibility of deterioration in the footings.

Masonry is undoubtedly the natural material for foundations, and the author believes that it should be preferred to iron or steel wherever practicable.

By the use of twisted iron rods the concrete footings may be made of equal transverse strength as footings of steel beams, but they require more height.

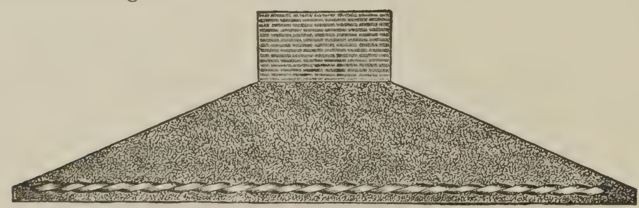


Fig. 13.

Fig. 13 shows the most economical section for a concrete and twisted iron footing. In building the footings with steel beams, the strength of the concrete is practically wasted, while in this method of construction it is all utilized. It has been proved that the entire tensile strength of the twisted bars can be utilized, and, being held continuously along their entire length by the concrete as a screw bolt is held by the nut, they neither draw nor stretch, except as the concrete extends with them.

In building concrete footings, as shown in Fig. 13, a layer of concrete from 3 to 6 inches thick, made in the proportion of 1 to 3, should first be laid, and the iron bars laid on and tamped down

* In cutting through a portion of a foundation built of concrete and iron, and submerged in salt water, ten years after the work was done, no deterioration to the iron whatever was found. Iron imbedded in concrete, with the end projecting, has been found bright and clean after the projecting end had completely rusted away.

into it. Another layer of 4 inches, mixed in the same proportion, should then be laid, after which the concrete may be mixed in the proportion of one to six. Each layer should be laid before the preceding layer has had time to harden, otherwise they may not adhere thoroughly.

The author has prepared Table III., giving the strength and proportions of footings constructed in this way, which he believes to have a large margin of safety. Two sizes of bars are given, with the corresponding safe loads for the footings, the other measurements applying to both cases. The measurements in the third column refer to the width of the brick or stone footing resting on the concrete. The greater the width of this footing in proportion to the width of the concrete, the less will be the strain on the tension rods.

TABLE III.—PROPORTIONS AND STRENGTH OF CONCRETE FOOTINGS WITH TWISTED IRON TENSION BARS.

WIDTH OF FOOTING IN FEET.	THICKNESS OF CONCRETE.		WIDTH OF STONE FOOTING.		DISTANCE BETWEEN CENTRES OF BARS.	SIZE OF SQUARE BAR.	SAFE LOAD PER LINEAL FOOT.	SIZE OF SQUARE BAR.	SAFE LOAD PER LINEAL FOOT.
	Ft.	In.	Ft.	In.	Inches.	Inches.	Tons.	Inches.	Tons.
20	3	6	6	0	8	2	78	$1\frac{7}{8}$	66
18	3	3	5	6	8	2	76	$1\frac{3}{4}$	56
16	2	10	5	0	7	$1\frac{3}{4}$	73	$1\frac{1}{2}$	50
14	2	8	4	8	7	$1\frac{5}{8}$	70	$1\frac{3}{8}$	49
12	2	6	4	4	6	$1\frac{3}{8}$	65	$1\frac{1}{4}$	48
10	2	3	4	0	6	$1\frac{1}{4}$	65	1	42
8	2	0	4	0	6	1	60	$\frac{3}{4}$	40
6	1	8	3	6	6	$\frac{3}{4}$	55	$\frac{1}{2}$	29

Piers.—Footings for piers may be built in the same manner, with two sets of bars laid crossways of each other, and also diagonally, as shown in Fig. 14. In the case of piers the corners should be cut off at an angle of 45 degrees, as shown. The same size of bars should be used for a pier as for a wall, whose footings have the same projection beyond the masonry, and the depth of the concrete should be the same.

Example.—What would be the safe load for a pier footing 14 feet square, with a stone footing on top 6 feet square, the corners being cut off, as in Fig. 14?

Answer.—The area of the pier footing would be $196-32=164$ square feet, and the projection of the footing beyond the masonry would be 4 feet. In Table III. we find that the projection of the 12-foot footings is 3 feet 10 inches, and that the safe load for this

footing (with $1\frac{1}{4}$-inch bars) is 48 tons, or 4 tons per square foot. If we make our pier of the same thickness and use $1\frac{1}{4}$-inch bars we would have the same strength per square foot, which would give a total safe load on the footing of 656 tons.

Unfortunately this method of construction, including all forms of concrete construction with twisted tension rods, has been patented by Ernest L. Ransome, of San Francisco, Cal., and the rights are now owned by the Ransome & Smith Co., of New York, Chicago and San Francisco, to whom a royalty must be paid when twisted bars are used; but even after paying the royalty it is much the cheapest footing for the strength obtained.

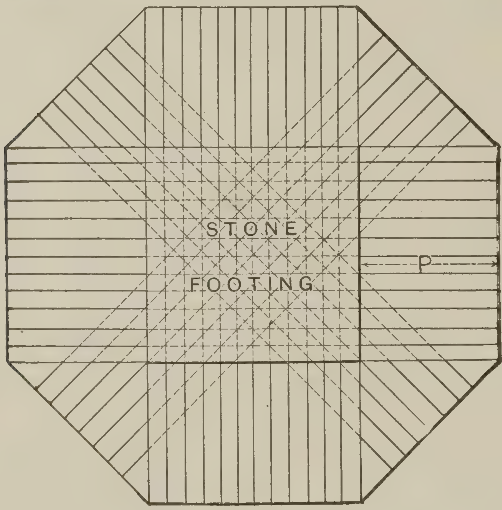


Fig. 14.—Plan of Pier.

This form of construction has been used to a considerable extent in San Francisco.

STEEL BEAM FOOTINGS.

49. When it is necessary to spread the foundations over 12 or 15 feet in each direction, with a very small height to the footings, as is the case in Chicago, steel beams must be used to furnish the necessary transverse strength. Even when building on solid ground, it is claimed that iron and steel footings for tall buildings, at the present price of steel (1895), are cheaper than masonry footings. The author doubts, however, if steel footings will prove as durable as those of masonry.

The manner of using the beams is shown in Figures 15 to 18.

In preparing the footings, the ground is first carefully leveled and the bottom of the pier located. If the ground is not compact enough to permit of excavating for the concrete bed without the sides of the pit or trench falling in, heavy planks or timbers should be set up and fastened together at the corners, and, if necessary, tied between with rods, to hold the concrete in place and prevent its spreading before it has thoroughly set. A layer of Portland cement concrete, made in the proportion of 1 to 6, and from 6 to 12 inches thick, according to the weight on the footings, should then be filled in between the timbers and well rammed and leveled off. If the concrete is to be 12 inches thick it should be put in in two layers. Upon this concrete the beams should be carefully bedded in 1 to 2 Portland cement mortar, so as to bring them nearly level and in line with each other.

The distance apart of the beams, from centre to centre, may vary from 9 to 20 inches, according to the height of the beams, thickness of concrete, and estimated pressure per square foot. They must not be so far apart that the beams will crush through the concrete (see Section 53), and on the other hand there must be a space of at least 2 inches between edges of flanges to permit the introduction of the concrete filling. As soon as the beams are in place the spaces between them should be filled with 1 to 6 concrete, the stone being broken to pass through a $1\frac{1}{2}$-inch ring, and the concrete well rammed into place, so that no cavities will be left in the centre. The concrete must also be carried at least 3 inches beyond the beams on sides and ends, and kept in place by planks or timbers.

50. If two or more layers of beams are used, the top of each layer should be carefully leveled (after the concrete has been put in place) with 1 to 2 Portland cement mortar, not more than $\frac{1}{2}$ inch thick over the highest beams, and in this the next layer of beams should be bedded, and so on.

The stone or metal base plate or footing should also be bedded in Portland cement mortar, not more than $\frac{3}{4}$ inch thick, above the upper tier of beams.

After the base plate or stone footing is in place at least 3 inches of concrete should be laid above the beams and at the sides and ends, and when this is set the whole outside of the footings should be plastered with 1 to 2 Portland cement mortar.

Mr. George Hill, Consulting Engineer, recommends that before laying the steel beams two thicknesses of tarred felt laid in hot asphalt should be spread over the concrete, and on top of this a layer of rich

cement mortar $1\frac{1}{2}$ inches thick, in which the beams should be placed. He also recommends that the whole ooting be covered with two coats of hot asphalt.

51. Before the beams are laid they should be thoroughly cleaned with wire brushes, and, while absolutely dry, either painted with iron paint or else heated and coated with two coats of asphalt. Before covering the beams with the concrete every portion of the metal should be carefully examined, and wherever the paint or asphaltum has been scraped off in handling, the iron should be thoroughly dried and the coating renewed.

Every pains should be taken to protect the beams from rusting, for, when unprotected, steel beams rust very quickly, and if once the beams were subjected to the rusting process it would probably not be long before the building commenced to settle.

52. When iron and concrete foundations were first used in Chicago railway rails were employed, on account of their lesser cost, to give the transverse strength.

The footings were built up with five or six layers of rails, placed at right angles to each other, each layer diminishing in number until the upper surface was stepped off small enough not to unduly exceed the proper size of the column base. As each layer of rails was laid, concrete was filled between and around them, and when completed the footing resembled a simple concrete pier.

The footings under the Rand and McNally Building (erected in 1891) were of this character, five layers of rails being used in most of the footings. In some of the footings the upper layer consisted of 12-inch beams.

Building up the footings in successive tiers, however, is not as economical in the use of the steel as when two layers of deep beams are used. The beams being large and smooth, the concrete does not unite with them to form a composite beam, as is the case in the Ransome construction; therefore, no dependence at all can be placed on the concrete for spreading the weight.

It should also be borne in mind that the beams spread the load over the ground only by their transverse strength, and they should, therefore, be used in the same way that they would be were the foundation reversed, the wall or column becoming the support and the ground the load.

53. When several beams are used in the upper course or layer there is a tendency to concentrate the weight on the outer beams of the upper layer, owing to the deflection of the beams below. The author therefore advocates the use of as few beams as practicable in

the upper course, and where the conditions will permit either a single built up girder or two heavy beams, and in the lower course the deepest beams consistent with economy. If the beams in the lower course permit of a spacing much greater than their height, a layer of rails should be imbedded in the top of the concrete to prevent the beams from breaking through. The rails, however, would in no way affect the stress or bending action in the beams.

For a further discussion of the use of steel beams in foundations, the reader is referred to an article by the author in *Architecture and Building* of Aug. 24, 1895.

Examples of steel beam and concrete footings are also given, with illustrations, in the *Engineering Record* of December 12, 1891, and June 1, 1895.

Method of Determining the Size of the Steel Beams.

54. A. *Under a Wall.*—As the duty of the beams is to distribute the load coming from the foundation wall or base plate evenly over the ground, so that the pressure on each square foot of the soil will

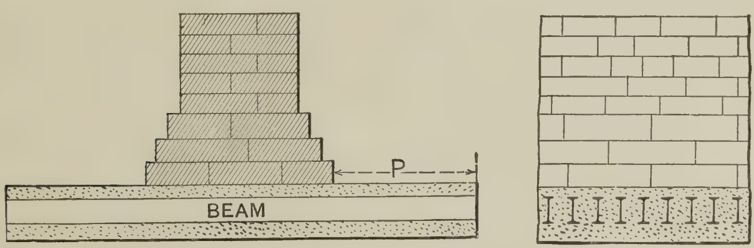


Fig. 15.

be the same, it is obvious that the beams must have sufficient transverse strength to keep them from bending, so that they will settle as much at the outer ends as under the centre. The effect on the beams shown in Fig. 15, when resting on a compressible soil and heavily loaded from above, is to cause the ends of the beams to bend upward, thus straining the beams most at the centre; the stress in the beams being the same as if they were supported at the centre and loaded with a distributed load. The maximum bending moment is also the same as for a beam fixed at one end and uniformly loaded, so that the beams are usually calculated by the formula for a beam fixed and loaded in that way.

The readiest method of determining the size of the beams is by computing the required *coefficient of strength* and finding in the tables of the manufacturers the size of beam which has a coefficient equal to or next above the value obtained by the formula. The *coefficient*

of strength, generally represented by the letter C, is given in the catalogues of the companies that roll beams, and may also be found in the tables of beams in the *Architects' and Builders' Pocket Book.*

The formula for the coefficient of strength for beams under a wall, as in Fig. 15, and also for the lower tier of beams under a pier, is

$$C=4\times w\times p^2\times s \qquad (1)$$

in which w represents the assumed bearing power in pounds per square foot; p, the projection of the beam in feet, and s, the spacing or distance between centres of beams, also in feet.

Owing to the tendency of the beams in bending, to concentrate the load on the outer edges of the masonry footing, and thus crush them, which action would have the same effect on the beam as lengthening the arm or projection (see article in *Architecture and Building* previously referred to), the author recommends that when the course above the beams is of stone, brick or concrete, at least one-third the width of the masonry footing *be added to the actual projection.* The calculations above indicated will be more clearly shown by the following example:

Example I.—A building is to be erected on a soil of which the safe bearing power is but 2 tons, and the pressure on each lineal foot of wall is 20 tons. It is decided to build the footings as shown in Fig. 15. What should be the dimensions and weight of the beams?

Answer.—As the total pressure under each lineal foot of wall is 20 tons, and the safe bearing power of the soil 2 tons, the footings must be $20\div2$, or 10 feet wide. We will use 4-foot granite blocks for the bottom course of the wall, which will give an actual projection (P) of 3 feet for the beams. For making the calculations we will add to the actual projection one-third of 4 feet, or 16 inches, making the value of p $4\frac{1}{3}$ feet. We will assume 1 foot for the spacing of the beams, so that s will equal 1. The beams must then have a coefficient of strength $=4\times w\times p^2\times s=4\times4000\times(4\frac{1}{3})^2\times1=304{,}000$ lbs. Examining the table giving the properties of Carnegie steel beams, we find that a 10-inch 33-pound steel beam has a coefficient of 344,000 pounds, and a 25-pound beam 261,000 pounds; therefore, we must use 33-pound steel beams 10 feet long. If we spaced the beams 10 inches on centres, s would equal $\frac{5}{6}$ and C would equal $4\times4000\times(4\frac{1}{3})^2\times\frac{5}{6}$, or 253,500 pounds, which would enable us to use 25-pound beams, thereby effecting a saving of 30 pounds to the lineal foot of wall.

55. To facilitate making the above calculations, the Carnegie Steel Company publishes the following table giving the *safe projection* of Carnegie steel beams, spaced 1 foot on centres, and for bearing values ranging from 1 to 5 tons:

TABLE IV.—SAFE PROJECTIONS IN FEET OF STEEL BEAMS IN FOUNDATIONS.

DEPTH OF BEAM.	WEIGHT PER FOOT.	BEARING POWER IN TONS PER SQUARE FOOT.										
		1	1¼	1½	2	2¼	2½	3	3½	4	4½	5
In.	Lbs.											
20	80.	14.0	12.5	11.5	10.0	9.0	9.0	8.0	7.5	7.0	6.5	6.0
20	64.	12.5	11.0	10.0	8.5	8.0	8.0	7.0	6.5	6.0	6.0	5.5
15	75.	11.5	10.5	9.5	8.0	7.5	7.5	6.5	6.0	6.0	5.5	5.0
15	60.	10.5	9.5	8.5	7.5	7.0	6.5	6.0	5.5	5.5	5.0	5.0
15	50.	9.5	8.5	8.0	7.0	6.5	6.0	5.5	5.0	5.0	4.5	4.5
15	41.	8.5	8.0	7.0	6.0	6.0	5.5	5.0	4.5	4.5	4.0	4.0
12	40.	8.0	7.0	6.5	5.5	5.5	5.0	4.5	4.0	4.0	3.5	3.5
12	32.	7.0	6.5	5.5	5.0	4.5	4.5	4.0	4.0	3.5	3.5	3.0
10	33.	6.5	6.0	5.5	4.5	4.5	4.0	4.0	3.5	3.5	3.0	3.0
10	25.5	5.5	5.0	4.5	4.0	4.0	3.5	3.5	3.0	3.0	2.5	2.5
9	27.	5.5	5.0	4.5	4.0	4.0	3.5	3.5	3.0	3.0	2.5	2.5
9	21.	5.0	4.5	4.0	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.0
8	22.	5.0	4.5	4.0	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.0
8	18.	4.5	4.0	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
7	20.	4.5	4.0	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
7	15.5	4.0	3.5	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	1.5
6	16.	3.5	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5
6	13.	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5
5	13.	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
5	10.	2.5	2.5	2.0	2.0	1.5	1.5	1.5	1.5	1.5	...	...
4	10.	2.5	2.0	2.0	1.5	1.5	1.5	1.5	...	...	...	...
4	7.5	2.0	2.0	1.5	1.5	1.5	1.5	...	...	...	...	...

Values given based on extreme fibre strain of 16,000 pounds per square inch.

By the use of this table no calculations are necessary except to determine the length and projection of the beams. If the beams are to be spaced more or less than 1 foot from centres, the bearing power must be increased or decreased in the same ratio in using the table. The results obtained by this table should agree with the result obtained from formula 1.

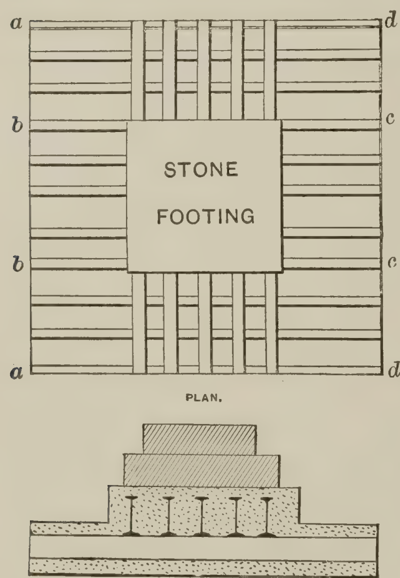
Thus, in the above example, to use the table, we simply look down the column headed *2* until we find the projection nearest to (above)

$4\frac{1}{2}$ feet, which in this case is 4.5, and opposite it we find a 10-inch, 33-pound beam.

To use the table for a spacing of 10 inches we must take five-sixths of the bearing power, or $1\frac{2}{3}$ tons. There is no column headed $1\frac{2}{3}$, but it would come between $1\frac{1}{2}$ and 2. For $1\frac{1}{2}$ tons the projection of a 10-inch, 25-pound beam is 4.5, and for 2 tons, 4 feet. At the same ratio the projection for $1\frac{2}{3}$ tons would be about 4.3 feet.

When there is no column corresponding with the bearing power it will be safer to use formula 1.

56. B. *Beams Under Piers* (Fig. 16).—In this case the size of the lower beams are determined in the same way as in Example I., the length of p being taken from the end of the beam to the centre of the outer beam in upper tier.



SECTION.

Fig. 16.

For the upper beams the load borne by each beam should be computed and the coefficient of strength determined by the formula

$$C = 4 \times W \times p \ldots\ldots\ldots (2)$$

W being in this case the total distributed load on either end of the beam in pounds, and p the distance from end of beam to edge of iron plate above.

Example II.—The basement columns of a ten-story building are required to sustain a permanent load of 400,000 pounds. What should be the size of the beams in the footings, the supporting power of the soil being but 2 tons?

Answer.—Dividing the load by the bearing power of the soil we have 100 square feet, or 10×10 feet, for the area of the footing. We will arrange the beams as shown in Fig. 16, using a cast iron bearing plate 3 feet square under the column. The distance between the centres of outer beams in upper tier we will make 32 inches, thus

making the value of p for the lower beams $= \frac{10'-2'\ 8''}{2}$ or $3\frac{2}{3}$ feet; s we will make 12 inches, or 1.

Looking down column headed 2 (Table IV.) we find the nearest projection above $3\frac{2}{3}$ is 4, which is opposite the 9-inch, 27-pound and also the 10-inch, 25.5-pound beams. The latter being the lighter and also the stiffer, we will use for the lower tier.

For the upper tier we see that the five beams must support an area equal to a, b, c, d, which in this case equals $3\frac{1}{2} \times 10$ feet, or 35 square feet. As the pressure on each foot is 2 tons, we will have a total pressure of 70 tons on the ends of the five beams, or 14 tons or 28,000 pounds on each beam. Then by formula 2 we find the coefficient of strength must $= 4 \times 28{,}000 \times 3\frac{1}{2} = 392{,}000$ pounds.

From the table of the Carnegie Steel Company's beams we find that the coefficient for a 12-inch, 32-pound beam is 395,200 pounds; therefore, we will use three 12-inch, 32-pound beams and two 40-pound beams in the upper tier.

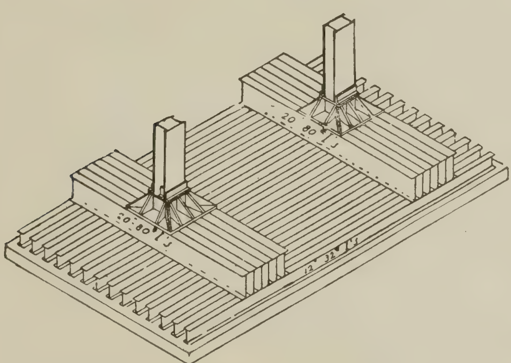


Fig. 17.

57. The deepest beam for the weight should always be used, and unless the beams in the upper tier have considerable excess of strength, the two outer beams should be heavy beams.

When the footings carry iron or steel columns in the basement, as is generally the case, a cast iron or steel base plate should be used, as shown in Figs. 17 and 18. This plate should be bedded in Portland cement directly above the beams, as described in Section 50.

Two and even four columns are often supported on one footing, as shown in Figs. 17 and 18. In such cases the computation becomes more elaborate, and an engineer should be called into consultation unless the architect is himself sufficiently familiar with such calculations.

Fig. 19 shows an arrangement in which a built-up base plate or girder is used in place of the upper tier of beams. The author

believes this arrangement much better than that shown in Figs. 16 to 18.

In placing the beams, it is essential that they be arranged symmetrically under the base plate, otherwise they will sink more at one side than at the other. When several unequally loaded columns rest on the same footing, the equal distribution of the weight on the soil becomes a difficult problem.

TIMBER FOOTINGS.

58. For buildings of moderate height timber may be used for giving the necessary spread to the footings, provided water is always present. The footings should be built by covering the bottom of the trenches, which should be perfectly level, with 2-inch plank laid

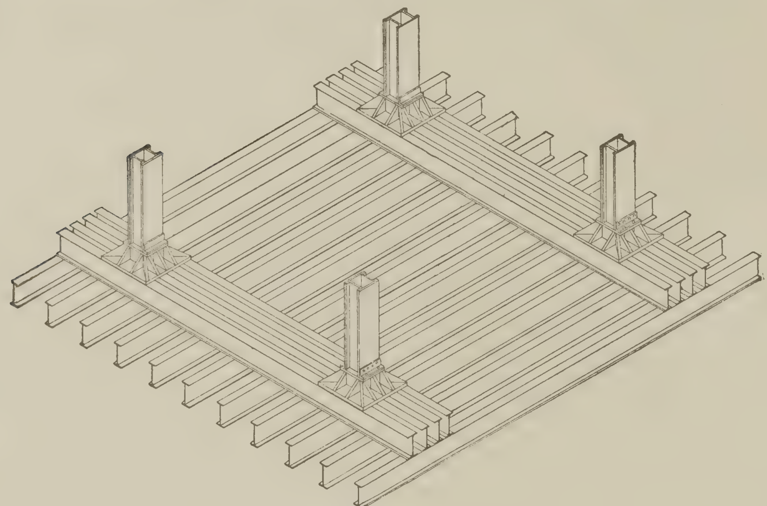


Fig. 18.

close together and longitudinally of the wall. Across these heavy timbers should be laid, spaced about 12 inches from centres, the size of the timbers being proportioned to the transverse strain. On top of these timbers again should be spiked a floor of 3 inch plank of the same width as the masonry footings which are laid upon it. A section of such a footing is shown in Fig. 20.

All of the timber work must be kept below low water mark, and the space between the transverse timbers should be filled with sand, broken stone or concrete. The best woods for such foundations are oak, Georgia pine and Norway pine. Many of the old buildings in Chicago rest on timber footings.

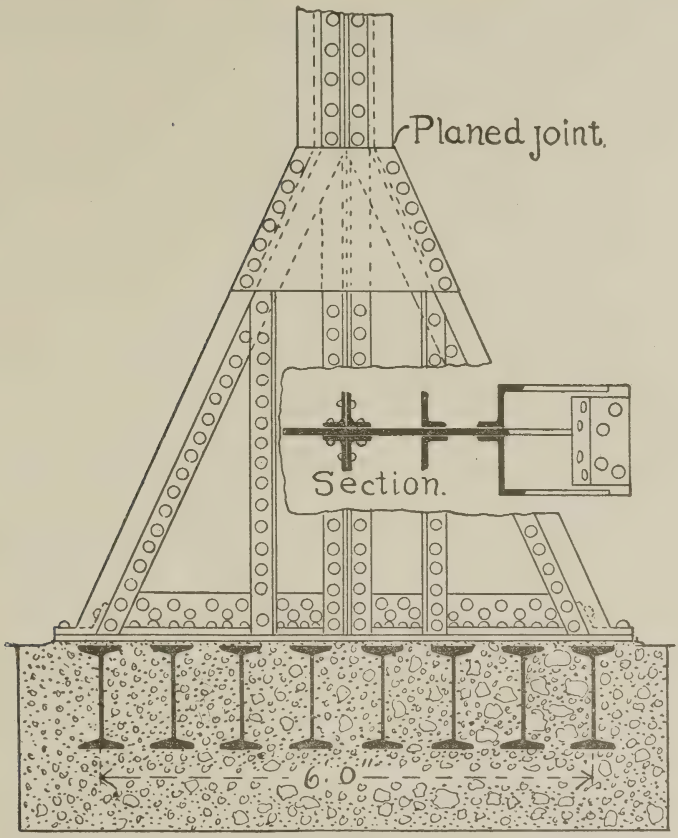

Planed joint.
Section.
6.0"

Fig. 19.

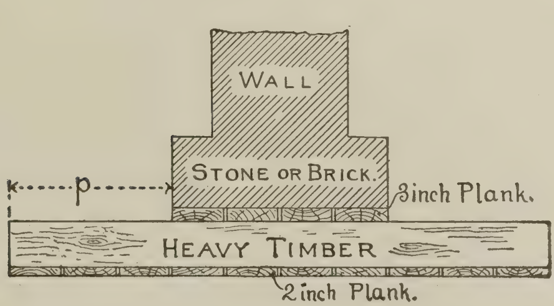

WALL
STONE OR BRICK.
p
3inch Plank.
HEAVY TIMBER
2inch Plank.

Fig. 20.

59. Calculation for the Size of the Cross Timbers.—The size of the transverse timbers should be computed by the following formula:

$$\text{Breadth in inches} = \frac{2 \times w \times p^2 \times s}{D^2 \times A} \ldots\ldots\ldots\ldots\ldots (3)$$

w representing the bearing power in pounds per square foot; p, the projection of the beam beyond the 3-inch plank in feet; s, the distance between centres of beams in feet, and D, the assumed depth of the beam in inches. A is the constant for strength, and should be taken at 90 for Georgia pine, 65 for oak, 60 for Norway pine and 55 for common white pine or spruce.

Example I.—The side walls of a given building impose on the foundation a pressure of 20,000 pounds per lineal foot; the soil will only support, without excessive settlement, 2,000 pounds to the square foot. It is decided for economy to build the footings as shown in Fig. 20, using Georgia pine timber. What should be the size of the transverse timbers?

Answer.—Dividing the total pressure per lineal foot by 2,000 pounds, we have 10 feet for the width of the footings. The masonry footing we will make of granite or other hard stone, 4 feet wide, and solidly bedded on the plank in Portland cement mortar. The projection p of the transverse beams would then be 3 feet. We will space the beams 12 inches from centres, so that $s=1$, and will assume 10 inches for the depth of the beams. Then by formula 3, breadth in inches $= \frac{2 \times 2000 \times 9 \times 1}{100 \times 90} = 4$, or we should use $4'' \times 10''$ timbers, 12 inches from centres. If common pine timber were used we should substitute 55 for 90, and the result would be $6\frac{1}{2}$.

60. *When building on quicksand* it is often advantageous to lay a floor of 1-inch boards in two or more layers at right angles to each other on which to start the concrete footings.

61. Foundations for Temporary Buildings.—When temporary buildings are to be built over a compressible soil, the foundations may, as a rule, be constructed more cheaply of timber than of any other material, and in such cases the durability of the timber need not be considered, as good sound lumber will last two or three years in almost any place if thorough ventilation is provided.

The World's Fair buildings at Chicago (1893) were, as a rule, supported on timber platforms, proportioned so that the maximum load on the soil would not exceed $1\frac{1}{4}$ tons per square foot. Only in a few places over "mud holes" were pile foundations used.

The platform foundations consisted of "3-inch pine or hemlock planks, with blocking (transverse beams) on top, to distribute the pressure from the loads uniformly over all the planks and to furnish support for the posts which carry the caps supporting the floor joists and posts of the building. The blocking was well spiked to platform planks and posts, and caps and sills drift bolted."

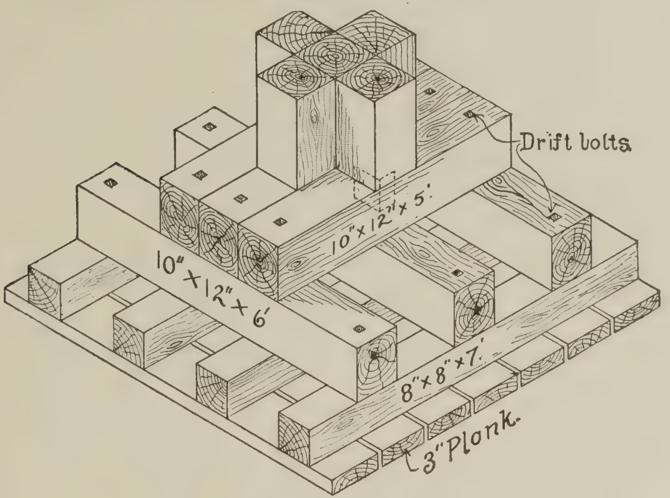


Fig. 21.

Fig. 21 shows the general arrangement of the blocking under the posts.

MASONRY WELLS.

62. When it is necessary to support very heavy buildings on compressible or filled soil, where piles or spread footings cannot be used, or are not considered desirable, wells of masonry, sunk to bed rock or hard pan, will generally prove the next cheapest method of securing an efficient foundation. The wells are arranged as isolated piers, and the walls of the superstructure carried on steel girders resting on these piers.

The manner in which such wells or piers should be used can probably be best explained by describing those under the City Hall of Kansas City, Mo., which was one of the first instances in which such wells were used in this country.*

* The following description is an abstract of a short paper presented by the architect of the building, Mr. S. E. Chamberlain, of Kansas City, to the twenty-fourth annual convention of the American Institute of Architects. The illustrations were prepared in the office of the *Engineering Record* from the architect's drawings. Several more illustrations are given in the *Engineering Record* of April 2 and 16, 1892.

"The site of the City Hall was formerly a ravine between abrupt bluffs. These had been so cut away and leveled as to leave a 50-foot filling of rubbish under two-thirds of the building and a solid clay bank under the other third. The fill was made by a public dump. Pile foundations were objectionable on account of the dryness of the fill and the anticipated tendency of the piles to rot therein. Ordinary trenching was considered too expensive and dangerous, therefore a system of piers was chosen, and a cylindrical form was adopted, so that the excavation could be done by a large steam power auger, followed by a $\frac{3}{16}$-inch caisson filled with vitrified brick. The caissons were made in 5-foot lengths of the same thickness throughout, the joints being made with $3'' \times \frac{1}{2}''$ splice plates, riveted to the inside of the shell.

"The piers were of vitrified brick, 4 feet 6 inches in diameter, laid in hydraulic cement mortar, grouted solid in each course, and well bonded in all directions. The piers were sunk to bed rock of oolitic limestone, 8 feet thick, and capped with cast iron plates (Fig. 22) and steel I-beams, which supported the walls. To the top of the beams was riveted a $\frac{1}{4}$-inch plate of boiler iron, on which the brickwork of the walls was built, as shown in Fig. 23.

"Between the beams, and 1 foot on each side and underneath them, is a concrete filling, so that the beams are entirely encased in masonry.

"Piers having excessive loads are reinforced by 12-inch Z-bar columns resting on rock bottom (Fig. 24). These columns pass through the cast iron caps, so that the loads resting on the columns are separate from those on the brick piers (an essential provision). Essentially the whole system is intended to secure the direct transmission of the entire weight to the solid rock by so arranging the interior construction that each subdivision is carried by an adequate isolated pier. The piers are of uniform size, and their loads are equalized by spacing them at proportionate distances apart."

63. Another instance of the use of masonry wells or deep piers is in the foundation of the new Stock Exchange in Chicago.

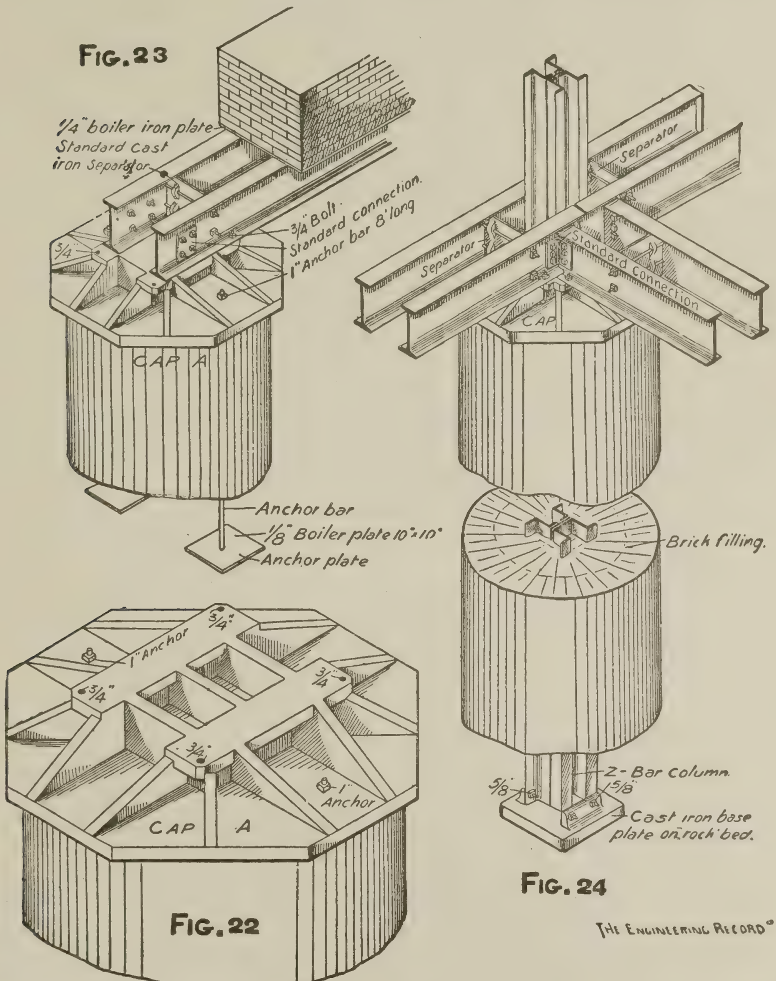
"The foundation is generally upon piles about 50 feet long, driven into the hard clay which overlies the rock. Next to the *Herald* Building, however, which adjoins it, wells were substituted, lest the shock of the pile driver close to its walls should cause settlements and cracks. A short cylinder, 5 feet in diameter, made of steel plate, was first sunk by hand, reaching below the footings of the *Herald* Building. Then around and inside the base of the cylinder sheet piles, about $3\frac{1}{2}$ feet long, were driven, and held in place by a ring of steel inside their upper ends. The material inside the sheeting was excavated and a similar steel ring was placed inside their lower ends. By means of wedges the lower ends of the sheeting were forced back into the soft clay until another course could be driven outside the lower ring. This operation was repeated until the excavation had reached the hard clay about 40 feet below the cellar. In this material the excavation was continued without sheeting in the form of a hollow truncated cone to a diameter of $7\frac{1}{2}$ feet, and the entire excavation was filled with concrete. The wells are spaced about 12 feet. The loads upon them vary; some of them will carry about 200 tons

"The material excavated was a soft, putty-like clay to a depth of 40 feet, where a firm clay was reached deemed capable of carrying the weight proposed." *

* "Foundations of High Buildings." By W. R Hutton, C. E., etc. Read before the Congress of Architects at Chicago, 1893.

CAISSONS.

64. Although caissons have been extensively used in constructing the foundations of bridge piers, they have as yet been used for the foundations of but few buildings in this country, the first instance



being the building for the Manhattan Life Insurance Company, near the foot of Broadway, New York City—Messrs. Kimball & Thompson, Architects; Charles O. Brown, Consulting Engineer.

As it is claimed that the method there employed proved perfectly satisfactory, and cost only about 8 or 9 per cent. of the estimated cost of the building, it is deemed of sufficient importance to merit a short description of the manner in which the foundations were constructed and the superstructure supported therefrom.*

"The building occupies an area of about 8,200 square feet, and is seventeen stories high on Broadway and eighteen on New Street. The height from the Broadway curb to the parapet of the main roof is 242 feet, and the dome and tower rises 108 feet above the parapet. All the walls, together with the iron floors and roof (which are very heavy), are directly supported by thirty-four cast iron columns, which sustain an estimated weight of about 30,000 tons.

"The great height and massive metal and masonry construction impose enormous loads on the foundations, amounting to as much as 200 tons for some single columns, and giving about 7,300 pounds per square foot over the whole area of the lot. This enormous weight could not be safely carried on the natural soil, which is essentially of mud and quicksand to the bed rock, which has a fairly level surface about 54 feet below the Broadway street level. Above this rock the water percolates very freely, standing at a level of about 22 feet below the Broadway street line, and therefore making excavations below this plane difficult and costly. If piles had been driven as close together as the city regulations permit—*i. e.*, 30 inches centre to centre over the whole area, about 1,323 might have been placed, and would have carried an average load of 45,300 pounds each, which was inadmissible, the statute laws of New York allowing only 40,000 pounds each on piles 2 feet 6 inches apart and with a smallest diameter of 5 inches.

"Special foundations were therefore necessary, and it was imperative that their construction and duty should not jeopardize nor disturb the existing adjacent heavy buildings which stand close to the lot lines. On the south side the six-story Consolidated Exchange Building is founded on piles which are supposed to extend to the rock. On the north the foundations of a four-story brick building rest on the earth about 28 feet above the rock, and were especially liable to injury from disturbances of the adjoining soil, which was so wet and soft as to be likely to flow if the pressure was much increased by heavy loading or diminished by the excavation of pits or trenches.

"In view of these conditions it was determined to carry the foundations on solid masonry piers down to bed rock. The construction of the piers by the pneumatic caisson process was, after careful consideration by the architects, backed by opinions from prominent bridge engineers as to its feasibility, adopted.

"The smaller caissons were received complete and the larger ones in convenient sections, bolted together when necessary, and located in their exact horizontal positions, calked and roofed with heavy beams to form a platform, on which the brick masonry was started and built up for a few feet before the workmen entered the excavating chamber and began digging out the soil. The removal of the soil allowed the caissons to gradually sink to the rock below without disturbing the adjacent earth, which was kept from flowing in by maintaining an interior pneu-

* The following is an abstract from a very full description, with ten illustrations, published in the *Engineering Record* of January 20, 1894.

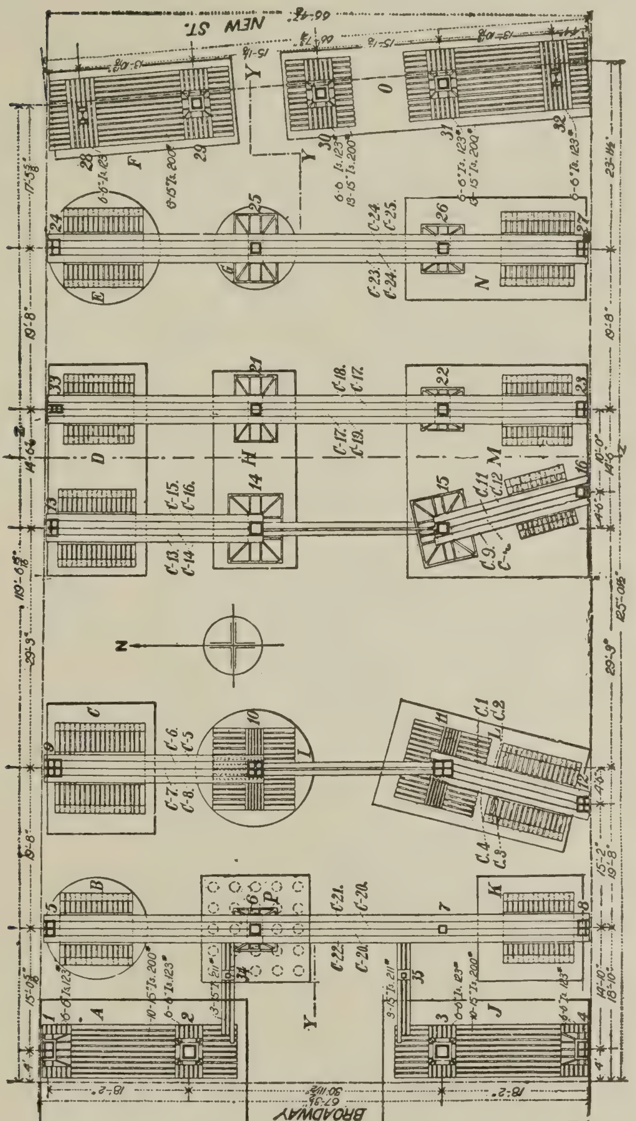


Fig. 25.—The Manhattan Life Insurance Building, New York City.—Plan of Piers.

PUBLISHED BY CONSENT OF THE ENGINEERING RECORD.

matic pressure slightly in excess of the outside hydrostatic pressure due to the distance of the bottom of the caisson below the water line.

"The adjacent buildings were shored up at the outset and scrupulously watched, observations being made to determine any possible displacement or injury of their walls, which were not seriously damaged, though the pressure they exerted on the yielding soil tended to deflect the caissons which were sunk within a foot of them. They were kept in position by excess of loading and excavating on the edges that

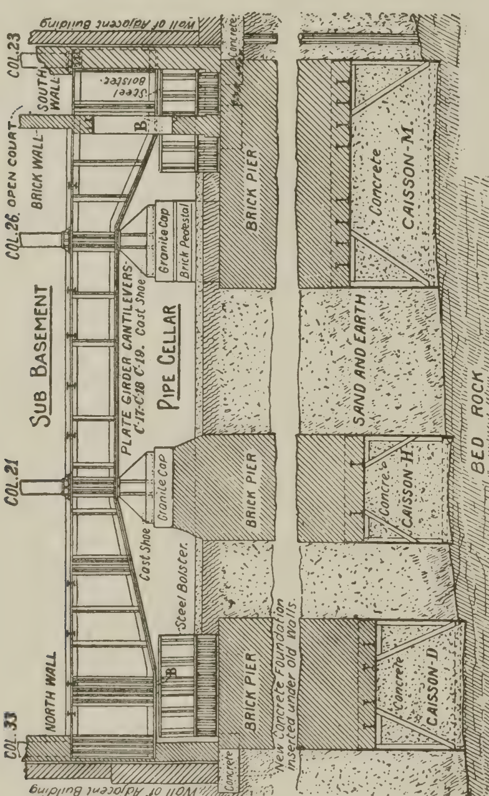


Fig. 26.—The Manhattan Life Insurance Building, New York City.—Transverse Section.*

tended to be highest. The caissons encountered boulders and other obstructions, and were sunk through the fine soil and mud at an average rate of 4 feet per day. No blasting was required until the bed rock was reached and leveled off under the edges and stepped into horizontal surfaces throughout the extent of the excavating chamber. Usually one caisson was being sunk while another was being prepared, there being only one time when air pressure was simultaneously maintained in two caissons. Generally about eight days were required to sink each caisson."

* Published by consent of the *Engineering Record*.

The first caisson was delivered at the site April 13, 1893, and the last pier was completed August 13, 1893.

"After the caissons were sunk to bed rock, and the surface cleared and dressed, the excavating chambers and shafts were rammed full of concrete, made of 1 part Alsen Portland cement, 2 parts sand and 4 parts of stone, broken to pass through a 2½-inch ring. The superimposed piers were built of hard-burned Hudson River brick, laid in mortar composed of 1 part Little Giant cement to 2 parts sand."

Fig. 25 is a plan showing the piers (all of which, except *P*, which is built on twenty-five piles, are founded on caissons of the same size) and the bolsters on top of them, together with the girders and the columns, which are indicated by solid block cross sections.

"Cylindrical caissons are the most convenient and economical, and would have been used throughout if the conditions had permitted, but the positions of the columns and the necessity of distributing the load along the building lines and other considerations determined the use of rectangular ones, except in four cases." All the caissons were 11 feet high, made of ½-inch and ⅝-inch plates and 6x6-inch angle framework, stiffened with 7-inch bulb angles, vertical brackets and reinforced cutting edges.

The columns supporting the outer side walls of the building were located so near the building line as to be near or beyond the outer edge of the foundation piers, as shown in Fig. 25, so that if they had been directly supported therefrom they would have loaded it eccentrically and produced undesirable irregularities of pressure. This condition was avoided and the weights transmitted to the centres of the piers by the intervention of heavy plate girders, which supported the columns in the required positions and transferred their weights to the proper bearings above the piers. From these bearings the load was distributed over the whole area of the masonry by special steel bolsters.

Fig. 26 is a transverse section at *D-H-M*, Fig. 25, showing the quadruple girder *C*, 17-18-19, and the manner in which it supports columns 23 and 33. The cantilever is made continuous across the building, with intermediate supports under columns 21 and 22.

Pneumatic caisson foundations were also used in the foundation construction of the American Surety Building, New York, a full description of which is given in the *Engineering Record* of July 14, 1894. Caisson foundations, whether in the shape of wells or of the pneumatic form, should only be used under the advice or direction of a competent engineer.

65. Foundations of High Buildings.—In preparing the foundations of high buildings the same principles apply as for other buildings, except that the loads on the foundations being so much greater the footings must be proportioned with the utmost care.

When building on firm soils it is only necessary to carefully observe all the precautions given in Chapter I., and on compressible soils one of the methods described in this chapter should be employed, always, however, under the advice of an experienced engineer.

Chapter III.

MASONRY FOOTINGS AND FOUNDATION WALLS, SHORING AND UNDERPINNING.

MASONRY FOOTINGS.

66. Footings under walls are used for two purposes: 1. To spread the weight over a greater area. 2. To add to the stability of the wall. Under buildings of only two or three stories, the latter function is generally the more important.

All walls should therefore have a footing or projecting course at the bottom of either brick, stone or concrete.

The width of the footings should be at least 12 inches wider than the thickness of the wall above, and also such that the pressure per square foot under the footing will not exceed the safe bearing power of the soil or the material on which it rests. (See Section 16.)

67. Concrete Footings.—For nearly all classes of buildings built on solid ground cement concrete makes probably the best material for the bottom footing course, especially for the money expended. Concrete possesses the advantage over large blocks of stone of having considerable transverse strength, so that when fully hardened it is much like a wide beam laid on top of the ground under the walls; and should a weak spot occur in the ground under the footing it would probably have sufficient transverse strength to span it if the spot were not very large. Concrete must also necessarily bear evenly over the bottom of the trenches, so that there can be no cavities, as is sometimes the case with stone footings. In localities where large blocks of granite or flagging cannot be cheaply procured, concrete makes much the cheapest footing.

In stiff soils trenches for the concrete footing should be dug below the general level of the excavation and of the exact width of the footings, so that when the concrete is put in and tamped it will bear against the sides as well as the bottom of the trench. In sandy soils this of course cannot be done, and planks must be set up and held in place by stakes to form the sides of the trench. After the cement has set, but not before, the planks may be removed.

Concrete for footings should be mixed in the proportion of 1 part cement to 2 of sand and 4 of stone for natural cements, and 1 to $2\frac{1}{2}$

and $5\frac{1}{2}$ for Portland cement. The thickness of the concrete should be one-fourth of its width, and never less than 12 inches, except under very light buildings. The concrete should be put in in layers about 6 inches thick. If the footing is considerably wider than the wall it may be stepped in by setting up plank to hold the upper layers of concrete, or a stone footing of proper width may be placed on top of the concrete, as in Fig. 27. The latter is apt to give the best results.

For the manner of mixing the concrete see Section 142 and specifications in Chapter X. For width of offsets see Section 70.

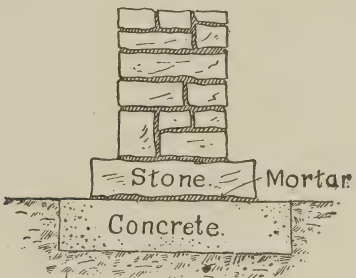


Fig. 27.

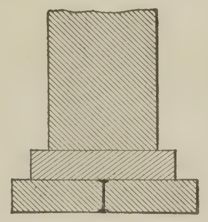


Fig. 28.

68. Stone Footings.—For buildings of moderate height stone footings are generally the most economical, and if they are carefully bedded, answer as well as concrete.

If practicable, the bottom footing course should consist of single stones of the full width of the footing, and the thickness of the stones should be about one-fourth of their width, depending much, however, upon the kind of stone. If stone of sufficient width cannot be obtained, the stone may be jointed under the centre of the wall, and a second course consisting of a single stone placed on top, as shown in Fig. 28.

For light buildings of only one or two stories, used for dwellings or similar purposes, irregular shaped stones, called "heavy rubble," are generally used, as shown in Fig. 29, which represents a plan of the footing course, the spaces between the larger stones being filled in with smaller stones. Each stone should be laid in mortar and the spaces between the stones solidly filled with mortar and broken stone.

Under heavy buildings the footing stones should be what are called "dimension stones," that is, they are roughly squared to certain dimensions. Dimension stones for footings may be obtained from 4 to 8 feet in length, according to the kind of stone. The width of the

stones, measured lengthways of the wall, should be at least 2 feet, or two-thirds the width of the footings.

The best stones for heavy footings are: Granite, bluestone, slate and some hard laminated sandstones and limestones.

69. *Bedding.*—As footing stones are generally very rough, being left as they come from the quarry, they cannot be made to bear evenly on the bottom of trenches without being bedded either in a thick bed of mortar, or, if the soil is sand or gravel, by washing the sand into the spaces by means of a stream of water. As a rule, the only safe way is to specify that the stones shall be set in a thick bed of cement mortar and worked around with bars until it is solidly bedded.

Fig. 29.

70. **Offsets.**—The projection of the footings beyond the wall, or the course above, is a point that must be carefully considered, whatever be the material of the footings.

If the projection of the footing or offset of the courses is too great for the strength of the stone, brick or concrete, the footing will crack, as shown in Fig. 30.

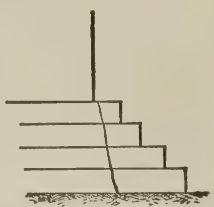


Fig. 30.

The proper offset for each course will depend upon the vertical pressure, the transverse strength of the material, and the thickness of the course. Each footing stone may be considered as a beam fixed at one end and uniformly loaded, and in this way the safe projection may be calculated.

Table V. gives the *safe offset for masonry footing courses, in terms of the thickness of the course*, computed by a factor of safety of 10.

TABLE V.

KIND OF FOOTING.	R. IN LBS. PER SQ. IN.*	OFFSET FOR A PRESSURE, IN TONS PER SQUARE FOOT ON THE BOTTOM OF THE COURSE, OF					
		0.5	1	2	3	5	10
Bluestone flagging	2,700	3.6	2.6	1.8	1.5	1.2	.8
Granite	1,800	2.9	2.1	1.5	1.2	1.	.7
Limestone	1,500	2.7	1.9	1.3	1.1	.9	.6
Sandstone	1,200	2.6	1.8	1.3	1.0	.8	.5
Slate	5,400	5.0	3.6	2.5	2.2	1.5	1.2
Best hard brick	1,200	2.6	1.8	1.3	1.0	.8	.5
Concrete { 1 Portland, 2 sand, 3 pebbles	150	0.8	0.6	0.4	....	....	....
Concrete { 1 Rosendale, 2 sand, 3 pebbles	80	0.6	0.4	0.3	....	....	....

* Modulus of Rupture, values given by Prof. Baker in "Treatise on Masonry Construction."

It should be borne in mind that as each footing course transmits the entire weight of the wall and its load, the pressure will be greater per square foot on the upper courses, and the offsets should be made proportionately less.

71. *Example.*—A 4-foot footing course of limestone transmits a load of 12 tons per lineal foot or 3 tons per square foot; the thickness of the course is 10 inches. What should be the width of the course above?

Answer.—From the table under the column headed 3 we find the projection to be 1.1 times the thickness, or in this case 11 inches. As we would have the same projection each side of the wall, the stone above may be 22 inches less in width, or 2 feet 2 inches wide. Except in cases where it is necessary to obtain very wide footings it

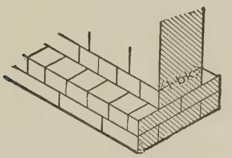


Fig. 31.

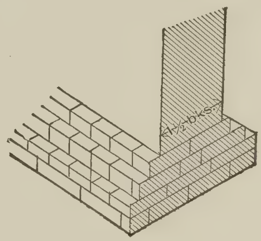


Fig. 32.

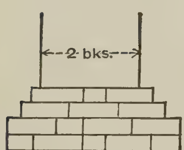


Fig. 33.

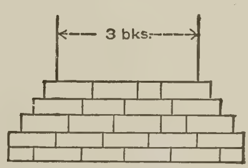


Fig. 34.

is better not to make the offsets more than 6 or 8 inches, and in the case above it would be better to make the upper footing course 3 feet wide. Most building ordinances require the projection of the footings beyond the foundation wall to be at least 6 inches on each side.

72. Brick Footings.—On sandy soils brick foundations and footings may be used when good stone cannot be cheaply obtained. In Denver, Col., where the soil is a mixture of sand and clay, very dry and unaffected by frost, brick foundations have been found to answer the purpose fully as well as stone for two and three-story buildings.

In building brick footings, the principal point to be attended to is to keep the back joints as far as possible from the face of the work, and in ordinary cases the best plan is to lay the footings in single courses ; the outside of the work being laid all headers, and no course projecting more than one-quarter brick beyond the one above it, except in the case of unloaded 9-inch walls. The bottom course should in all cases be a double one. Figs. 31–34 show the proper arrangement of the brick in walls from one to three bricks in thickness. If the ground is soft and compressible, or the wall heavily loaded, the footings should be made wider, as shown in Fig. 35. For brick footings under high walls, or walls that are very heavily loaded, each projecting course should be made double, the heading course above and the stretching course below.

The bricks used for footings should be the hardest and soundest that can be obtained, and should be laid in cement or hydraulic lime mortar, either grouted or thoroughly slushed up, so that every joint shall be entirely filled with mortar. The writer favors grouting brick walls, that is, using thin mortar for filling the inside joints, as he has always found it to give very satisfactory results.

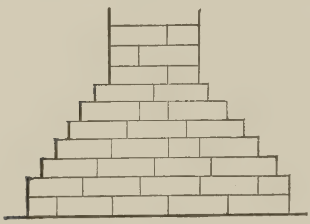


Fig. 35.

The bottom course of the footing should always be laid in a bed of mortar spread on the bottom of the trench, after the latter has been carefully leveled. All bricks laid in warm or dry weather should be thoroughly wet before laying, for, if laid dry, the bricks will rob the mortar of a large percentage of the moisture it contains, greatly weakening the adhesion and strength of the mortar.

Too much care cannot be bestowed upon the footing courses of any building, as upon them depends much of the stability of the work. If the bottom courses are not solidly bedded, if any seams or vacuities are left in the beds of the masonry, or if the materials themselves are unsound, the effects of such carelessness are sure to show themselves sooner or later, and almost always when they cannot be well remedied. Nothing is more apt to injure the reputation of a young architect than to have a building constructed under his direction settle and crack, and he should see personally that no part of the foundation work is in any way slighted.

73. Inverted Arches.—Inverted arches are sometimes built under and between the bases of piers, as shown in Fig. 36, with the idea of distributing the weight of the piers over the whole length of the footings. This method is objectionable—first, because it is nearly impossible to prevent the end piers of a series from being pushed outward by the thrust of the arch, as shown by the dotted line, and second, it is generally impossible with inverted arches to make the areas of the different parts of the foundation proportional to the load to be supported. It is much better to build the piers with separate footings, projecting equally on all four sides of the pier and proportioned to the load supported by the piers. The intermediate wall may either be supported by steel beams or arches, as preferred.

In some instances, however, when building on comparatively soft soils, and where it is impracticable to use spread footings, inverted

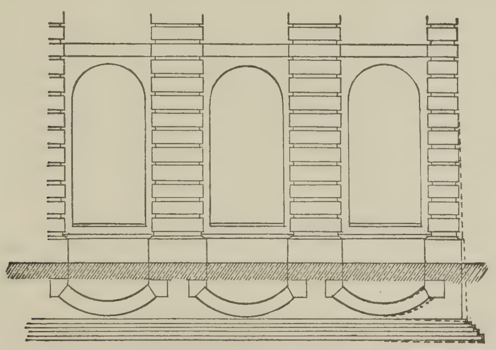


Fig. 36.

arches may be advantageously used, especially when it is necessary to reduce the height of the footing to a minimum.

If it is decided to use inverted arches, the foundation bed should be leveled and a footing built over the whole bed to a depth of at least 12 to 18 inches below the bottom of the arch. Concrete is much the best material for this footing, although brick or stone may be used if found more economical. The upper surface of the footing should be accurately formed to receive the arch. The arch should be built of hard brick, laid in cement mortar, and generally in separate rings or rowlocks, and should abut against stone or concrete skewbacks, as shown in Fig. 37.

It is better to build the arches before putting in the skewbacks, and for the latter 1 to 6 Portland cement concrete possesses special

advantages, as the concrete can be deposited between the ends of the arches and rammed evenly and simultaneously, thus giving a solid and uniform bearing against the ends of the arches, tending to prevent unequal settlement and cracking.

74. Above the concrete skewback a solid block of stone should be placed if it can be readily obtained. The thickness of the arch ring should be at least 12 inches, and heavy iron plates or washers should be set in the middle of the concrete skewbacks and connected with iron or steel rods, to take up the thrust of the end arches. The

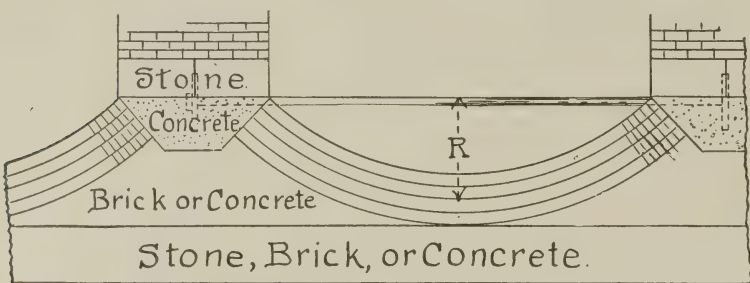


Fig. 37.

"rise" of the arch, or distance R, Fig. 37, should be equal to from one-fourth to one-sixth of the span. The sectional area of the arch should equal the result obtained by the following formula:

$$\text{Section of arch in sq. inches} = \frac{\text{Total load on arch (in lbs.)} \times \text{span}}{8 \times R \times 10}$$

and the area of the tie rods should equal

$$\frac{\text{Total load on arch (in lbs.)} \times \text{span}}{8 \times R \times 850} \text{ for wrought iron}$$

and

$$\frac{\text{Total load on arch} \times \text{span}}{8 \times R \times 1050} \text{ for steel,}$$

the span being measured in *feet*, and the distance R *in inches*.

The load on the arch will be equal to the span multiplied by the pressure per *lineal* foot imposed on the soil. The latter will be obtained by dividing the load on the piers by the distance between centres of piers.

75. *Example.*—It is desired to use inverted arches between the piers of a three-story building, resting on a soil whose bearing power

cannot be safely estimated at over 3,000 pounds per square foo The piers are of stone, 4 feet long, 22 inches thick, and 14 feet apart from centres. Each pier supports a total load of 98,000 pounds. What should be the sectional area of the arch, and of the rods in end spans?

Answer.—The span of the arch will be 10 feet, and the distance R about one-fifth of 10 feet, or 24 inches. The load per lineal foot on the soil will equal 98,000÷14, or 7,000 pounds. The footing under the arch must therefore be 2 feet 4 inches wide to reduce the pressure to 3,000 pounds per square foot. The width of the arch itself we will make 22 inches, or two and one-half bricks. The total load on the arch will equal 10×7,000, or 70,000 pounds

The sectional area of the arch must therefore equal

$$\frac{70000 \times 10}{8 \times 24 \times 10} \text{ or } 354 \text{ square inches.}$$

As the width is 22 inches, the depth must equal 354÷22, or 16 inches, which will require four rowlocks or rings.

The sectional area of the ties must equal, for wrought iron,

$$\frac{70000 \times 10}{8 \times 24 \times 850} \text{ or } 4.3 \text{ square inches.}$$

In this case it will be better to use two rods of 2.15 square inches in area, or say two $1\frac{3}{4}$-inch rods.

All cast iron work in the foundation should be coated with hot asphalt, and the rods should be dipped in linseed oil while new and hot and afterward painted one heavy coat of oxide of iron or red lead paint.

FOUNDATION WALLS.

76. This term is generally applied to those walls which are below the surface of the ground, and which support the superstructure. Walls whose chief office is to withhold a bank of earth, such as around areas, are called retaining walls.

Foundation walls may be built of brick, stone or concrete, the former being the most common. Brick walls for foundations are only suitable in very dry soils, or in the case of party walls, where there is a cellar or basement each side of them.

As the method of building brick foundations is the same as for any brick wall, it will not be described here, but taken up in the chapter on Brickwork. For concrete walls see Chapter XII.

77. *Stone Walls.*—The principal points to be watched in building a stone foundation wall are the character of the stone and mortar, bonding, filling of voids and pointing.

The best stones for foundations are granites, compact sandstones, slates and blue shale. The less porous the stone the better it will stand the dampness to which it must be subjected. As a rule laminated stones make the best wall, as they split easily and give flat and parallel beds. If the only stone to be had is boulders or field stone, they should be split so as to form good bed joints. Cobble or round stones should never be used for building foundation walls, and for all buildings exceeding three stories in height, block stone or the best qualities of laminated stone should be used.

The mortar for foundation walls below the grade line should be made either of natural cement, or hydraulic lime, and coarse sand; above grade good common lime, or lime and cement, may be used.

The usual practice in building foundations is to use the stone just as it is blasted from the quarry, or, if the building is built on a ledge, from the foundation itself, the stone receiving no preparation other than breaking it up with a sledge hammer, and squaring one edge for the face. Too great irregularity and unevenness is overcome by a sparing use of the stone hammer and by varying the thickness of the mortar joint in which the stones are bedded. The strength of the wall, therefore, depends largely upon the quality of the mortar used.

The wall should be leveled off about every 2 feet, so as to form irregular courses, and the horizontal joints should be kept as nearly level as possible.

When block stone is used the stones are generally from 18 inches to 2 feet thick and the full width of the wall. They are commonly roughly squared with the hammer, and but little mortar is used in the wall. Only in a few localities, however, are such stones obtainable at a price that will permit of their use, so that as a rule stone split from a ledge and called "rubble" is the material with which the architect will have to deal.

78. *Bonding.*—Aside from the quality of the stone and mortar, the strength of a rubble wall depends upon the manner in which it is bonded or tied together by lapping the stones over each other. About every 4 or 5 feet in each course a bond stone should be used; that is, a stone that will go entirely through the wall, and, by its friction on the stones below, hold them in place. A stone that goes three-fourths of the way through the wall is called a three-quarter

bond. It is usually customary to specify that there shall be at least one through stone in every 5 or 10 square feet of the wall, depending upon the character of the stone and nature of the building. Fig. 38 shows a portion of wall built of square or laminated stone, with through bond stone, *B B*, and three-quarter bond stones at *A A*. A good three-quarter bond is nearly equal in strength to a through bond, and when the character of the stone will permit of the wall being built largely of flat stone extending two-thirds of the way through the wall, it will not be necessary to use more than one through stone to every

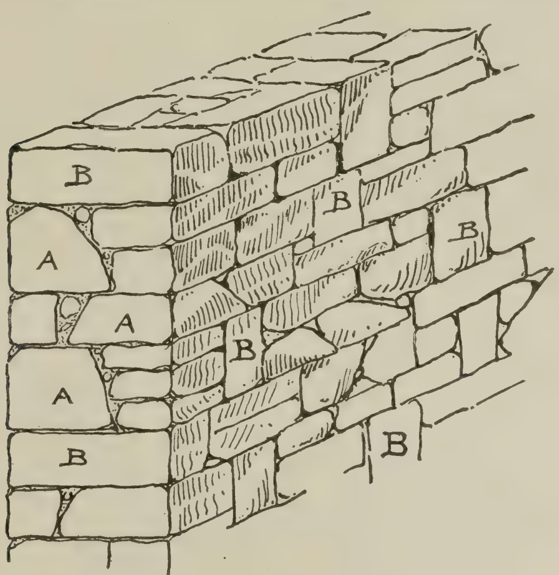


Fig. 38.

10 square feet of wall. No stone should be built into the face of a wall with a less depth than 6 inches, although stone masons will often set a stone on edge, so as to make a good face and give the appearance of a large stone, when it may be only 3 inches thick. All kinds of stones should always be laid so that their natural bed, or splitting surface, will be horizontal. It is also important that the stones shall break joint longitudinally, as in Fig. 38, and not have several vertical joints over each other, as at *A A*, Fig. 39. The angles of the foundation should be built up of long stone, laid alternately header and stretcher, as shown in Fig. 40. The largest and best stone should always be put in the corners, as these are usually the weakest part of the wall.

79. Filling of Voids.—All stones, large and small, should be solidly bedded in mortar, and all chinks or interstices between the large stones should be partially filled with mortar and then with small pieces of stone, or spalls, driven into the mortar with the trowel, and then smoothed off on top again with mortar.

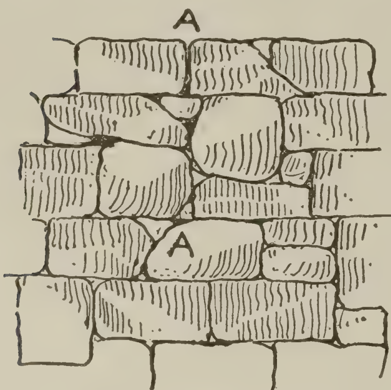


Fig. 39.

Many masons are apt to build the two faces of the wall with long, narrow stones and fill in between with dry stone, throwing a little mortar on top to make it look well.

A horizontal section through such a wall would appear as shown in Fig. 41. Such a wall would require but little loading to cause the outside faces to bulge, owing to the lack of strength in the middle portion. The way in which a wall of irregular shaped stones should be built to get the most strength is shown in Fig. 42.

Such a wall requires no more stone than the other, but requires

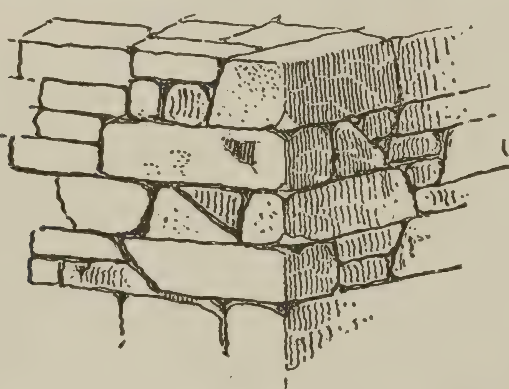


Fig. 40.

more *lifting* and a little more use of the hammer, and these appear to be the real reasons why better work is not more generally done.

80. Window Openings.—If there should be a window or door opening in the foundation wall, as in Fig. 43, the stones just below

the opening should be laid so as to spread the weight of the wall under the opening, as shown by the stones *A B C.* If there is to be any great weight come upon the foundation it will be better not to build the window sills into the wall, but to make their length just equal to the width of the opening, or slip sills, as they are called, then there will be no danger of their breaking by uneven settlement of the wall.

Fig. 41.

Fig. 42.

Occasionally part of the foundation wall of a building goes down much lower than the adjoining portion, and, as there is almost always a slight settlement in the joints of the wall, unless laid in cement the deeper wall will naturally settle more than the other, and thus cause a slight crack. This can be avoided by building the deeper wall of larger stone, so

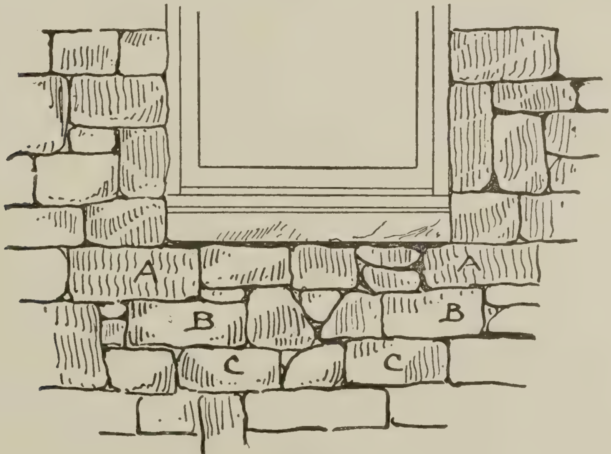


Fig. 43.

that there will be no more joints than in the other wall, or by making thin joints and using cement mortar.

81. Thickness of Foundation Walls.—The thickness of the foundation wall is usually governed by that of the wall above, and also by the depth of the wall.

Nearly all building regulations require that the thickness of the foundation wall, to the depth of 12 feet below the grade line, shall be 4 inches greater than the wall above for brick and 8 inches for stone, and for every additional 10 feet, or part thereof deeper, the thickness shall be increased 4 inches. In all large cities the thickness of the walls is controlled by law. For buildings where the thickness is not so governed the following table will serve as a fair guide:

TABLE VI.—THICKNESS FOR FOUNDATION WALLS.

HEIGHT OF BUILDING.	DWELLINGS, HOTELS, ETC.		WAREHOUSES.	
	BRICK.	STONE.	BRICK.	STONE.
	Ins.	Ins.	Ins.	Ins.
Two stories	12 or 16	20	16	20
Three stories	16	20	20	24
Four stories	20	24	24	28
Five stories	24	28	24	28
Six stories	24	28	28	32

Only block stone, or first-class rubble, with flat beds, should be used in foundations for buildings exceeding three stories in height. The footings should be at least 12 inches wider than the width of the walls. (See Section 66.)

In heavy clay soils it is a good idea to batter the walls on the outside, making the wall from 6 inches to a foot thicker at the bottom that it is at the top, and plastering the outside with cement. (See Fig. 3, Section 10.)

RETAINING WALLS.

82. A retaining wall is one that is built to hold up a bank of earth, which is afterward deposited behind it. Retaining walls differ from foundation walls, in that the latter support a superstructure whose weight is generally sufficient to overcome the thrust of the earth against the wall. A retaining wall, on the other hand, depends upon its own stability to resist the earth pressure.

True retaining walls are seldom designed by the architect, as the only place for which he would be likely to plan such walls is for the support of terraces, etc.

Area walls, it is true, generally serve as retaining walls, but as they are usually braced by arches or cross walls from the building wall, they do not require the same thickness as a retaining wall proper. Several theoretical formulæ have been evolved by writers on engineering subjects for computing the necessary thickness and most

economical section of retaining walls, but so many variable conditions enter into the designing of such walls, such as the character and cohesion of the soil, the amount the bank has been disturbed, the manner in which the material is filled in against the wall, etc., that little confidence is placed in these theoretical formulæ by practical engineers, and they appear to be guided more by empirical rules, derived from experience.

The cross section that appears to be most generally approved for retaining walls, particularly in engineering work, is shown in Fig. 44.

The wall may either be built plumb, as shown, or inclined toward the bank. The latter method is generally considered as securing greater stability, although it is open to the objection that the water which runs down the face of the wall is apt to penetrate into the inclined joints.

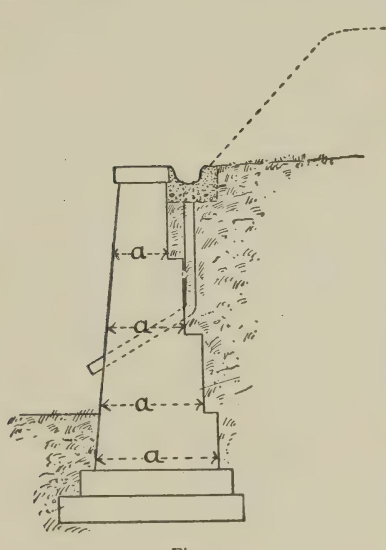


Fig. 44.

Retaining walls should be built only of good hard split or block stone,* laid in cement mortar and carefully bonded, to prevent the stones from sliding on the bed joints.

The thickness of the wall at the top should be not less than 18 inches, and the thickness, *a*, just above each step should be from one-third to two-fifths of the height from the top of the wall to that point.

If the earth is banked above the top of the wall, as shown by the dotted line, Fig. 44, the thickness of the wall should be increased. A thickness equal to one-half of the height will generally answer for a height of embankment equal to one-third that of the wall.

The outer face of the wall is generally battered, or sloped outward, about 1 inch to the foot.

Stepping the wall on the back increases the stability by bonding the wall into the material behind and having its weight increased by the weight of the soil resting upon the steps.

If built upon ground that is affected by frost or surface water, the

* Or Portland cement concrete with twisted iron bars.

footings should be carried sufficiently below the surface of the ground at the base of the wall to insure against heaving or settling.

If the ground back of the wall slopes toward the wall a cement gutter should be formed behind the coping and connected with a drain pipe to carry off the surface water. The back of the wall and tops of steps should be plastered with cement to the depth of at least 3 or 4 feet.

AREA WALLS.

83. Areas are often excavated outside the foundation walls of buildings to give light or access to the basement, and require to be surrounded by a wall to retain the bank and present a neat appearance.

Such walls should be built of stone, as a stone wall offers greater resistance, when the mortar is green, to sliding on the bed joints than a brick wall.

In making the excavation the bank should be disturbed as little as possible, and in filling against the wall the soil should be deposited in layers and well tamped, and not dumped carelessly behind the wall. The filling should also be delayed until the mortar has had time to harden, or else the wall should be well braced.

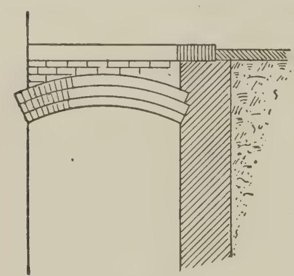


Fig. 45.

Area walls are commonly built in the same manner as foundation walls and of a uniform thickness, generally about 20 inches for a depth of 7 feet. If more than 7 feet in height the wall should have a batter on the area side and should be increased in thickness at the bottom, so that the average thickness of the wall will be at least one-third of the height, unless the wall is braced by arches, buttresses or cross walls.

Area walls sustaining a street or alley should be made thicker than those in an open lot.

When an area wall is more than 10 feet long it is generally practicable to brace it from the basement wall by arches thrown across from one wall to the other, as shown in Fig. 45. When this cannot be done the wall should be stiffened by buttresses about every 10 feet.

VAULT WALLS.

84. In large cities it is customary to utilize the space under the sidewalk for storage or other purposes. This necessitates a wall at the curb line to sustain the street and also the weight of the sidewalk.

Where practicable, the space should be divided by partition walls about every 10 feet, and when this is done the outer wall may be advantageously built of hard brick in the form of arches, as shown in Fig. 46.

The thickness of the arch should be at least 16 inches for a depth of 9 feet, and the "rise" of the arch one-sixth of the span.

If partitions are not practicable, each sidewalk beam may be supported by a heavy I-beam column, with either flat or segmental arches between, as shown in Fig. 47.

This latter method is more economical of space than any other, and where steel is cheap is about as economical in cost.

SUPERINTENDENCE OF FOUNDATION WORK.

85. The first work on the foundations will be putting in the footings.

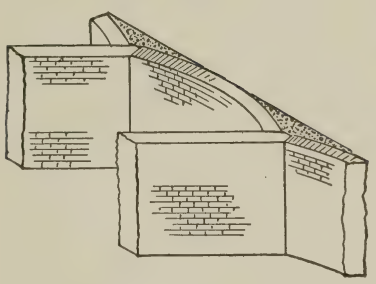


Fig. 46.

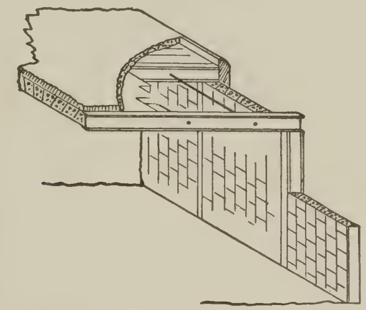


Fig. 47.

If the footings are of concrete, an inspector should be put on the work to stay during the entire working hours, and see that every batch of concrete is mixed in exactly the proportion specified, and that the aggregates are broken to the proper size and the cement all of the same brand and in good condition. There is no building operation that can be more easily "skimped" without detection than the making of concrete, and the only way by which the architect can be sure that his specifications have been strictly followed is by keeping a reliable representative constantly on the ground. The inspector should also see that the concrete is put in to the full thickness shown on the drawings, and that it is leveled and tamped every 6 inches in depth.

Should water be encountered in the trenches, it should be collected in a shallow hole and removed by a pump or drain, as explained in

Section 31. Very often, when the foundation rests on the top of a ledge, underlying gravel or clay, running water will be encountered in the trenches in too great a volume to be readily removed. In such a case, the flow of the water should be intercepted by a drain and cesspool, and a tight drain carried from the latter to a sewer or to a dry well below the foundation of the building.

Concrete footings for piers not more than 4 or 5 feet square may be built, where there is running water, by making large bags of oiled cotton and sinking them in the pit, filling the concrete into them immediately. The water will probably rise around the bag, but if the latter keeps the water away from the concrete until the cement has had time to set, it will have answered its purpose. Water does not injure concrete, or mortar made of cement, after it has begun to harden, but if freshly-mixed concrete is thrown into water the water separates the cement from the sand and aggregates, the cement mixing with the water and floating away, while the sand and stone drops to the bottom. For this reason concrete should never be thrown into trenches containing water.

86. If the footings are of stone the presence of water does not do as much harm, provided the water can be drained so as not to attain a greater depth than 3 or 4 inches. Sometimes the bottom of the wall is used as a drain for collecting the seepage water, and the trench is partially filled with stones laid without mortar, as explained in Section 10.

For heavy buildings, however, the footings should be solidly bedded in cement mortar when the trenches are reasonably dry, and when this is not the case, in sand or fine gravel. An irregular footing stone can often be bedded more solidly by piling fine sand around it and then washing the sand under the stone with water, than it can in cement mortar. The former method, however, takes more time, and would seldom be employed where mortar could be used as well.

As stated in Section 72, too much care cannot be bestowed upon the footing courses of any building, and there is no portion of the building that needs closer inspection than the footings and foundation.

Before the masons commence actual operations the architect should inspect all materials that have been delivered, to see that they are of the kind and quality specified.

The mortar, together with the sand, cement or lime, should be particularly examined, to see that the mortar has the proper proportions of cement or lime, and is well worked; that the cement or lime is fresh and all of the kind or brand specified; and that the sand is

clean and sharp. The building of the foundation wall should also be carefully watched to see that the wall is well tied together with plenty of three-quarter and through bond stones, and that the inside is solidly filled with stone and mortar.

The superintendent must also examine the wall occasionally to see that it is built straight and plumb, and that the general bed of the courses is horizontal.

When inspecting stonework already built, but which has not had time for the mortar to harden, a light steel rod, about $\frac{3}{16}$ inch in diameter and 4 or 5 feet long, will be found useful. If the rod can be pushed down into the centre of the wall more than 18 inches or 2 feet in any place it shows that the stones have not been lapped over each other, and if this can be done in several places the inspector should order the wall taken down and rebuilt. The rod will also indicate to a considerable extent whether or not the stones in the centre of the wall have been well bedded, as if they have not they will rock or tip when struck with the rod.

The inspection of a foundation wall cannot be too thorough, as there is nothing that causes an architect so much trouble as to have settlements in the foundations of his buildings.

87. Filling in.—In buildings where the cellar floor is 6 feet or more below the ground level the trenches behind the walls should not be filled in until the floor joists are on and the wall built 6 feet or more above them, or until the walls are solidly braced with heavy timbers, otherwise the wall may be sprung by the pressure of loose dirt. In heavy clay soils it is a good idea to fill in back of the wall with coarse gravel, stone spalls and sand, as frost will not "heave" them as it does clay.

Holes for Soil and Supply Pipes.—In thick walls, and when built of heavy stone, the architect should locate the position of the soil and supply pipes, and see that openings are left in the proper places for the pipes to pass through the wall.

DAMPNESS IN CELLAR WALLS.

88. In many localities it is necessary to guard against dampness in cellar walls, particularly in buildings where the basement is used for living rooms or for storage. There are several devices for preventing moisture from entering the walls, one class being in the nature of applications to the outside of the wall and the other being constructive devices.

Where only surface water is to be provided against, and the ground is not generally saturated with water, coating the outside of the wall with asphalt or Portland cement will, in most cases, prove a preventative against dampness.

Asphalt, applied to the outside of the wall while boiling hot, is generally considered as the most lasting and durable of all coatings. To insure perfect protection, the wall should have been built as carefully as possible, the joints well pointed and the whole allowed to get dry before the coating is applied.

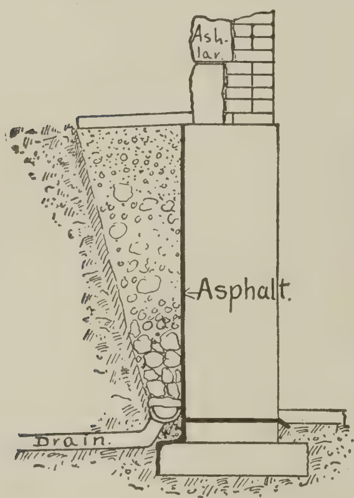


Fig. 48.

The asphalt should be applied in two or more coats and carried down to the bottom of the footings.

If the soil is wet and generally saturated with water, moisture is apt to rise in the wall by absorption from the bottom. To prevent this, two or three thicknesses of asphaltic felt, laid in hot asphalt, should be bedded on top of the footings, just below the basement floor, as shown by the heavy line, Fig. 48.

Portland cement may be used in place of asphalt if the ground is not exceeding damp, but if it is often saturated with water asphalt should be used. The objections to Portland cement are that it is easily fractured by any settlement of the walls, and being to some degree porous, suffers from the action of frost.

Common coal tar is also often used for coating cellar walls; it answers the purpose very well for a time, but gradually becomes brittle and crumbles away.

89. Of the constructive devices, the simplest is to make the excavation about 2 feet larger each way than the building, so that there will be about a foot or 10 inches between the bottom of the bank and the wall, as shown in Fig. 48. A V-shaped tile drain should be placed at the bottom of this trench after the wall is built and connected with a horizontal drain, carried some distance from the building.

The trench should then be filled with cobbles, coarse gravel and sand. If the top, for a distance of about 2 feet from the building, is covered with stone flagging or cement, it will assist greatly in keeping the walls dry.

By draining the soil in this way, and also coating the wall with asphalt or concrete, a perfectly dry wall will in most cases be insured

For greater protection of the basement from dampness, the basement walls should be lined with a 4-inch brick wall with an air space between the main wall and the lining, or an area should be built all around the outside walls.

WINDOW AND ENTRANCE AREAS.

90. These features, although not strictly a part of the foundations, are intimately connected with them, and are generally included in the same contract.

The thickness and bracing of area walls has already been considered (see Section 83). The materials and workmanship of the walls should bē the same as in the foundation walls.

Window areas intended for light and ventilation should be of ample size, so as not to obstruct the light more than possible.

For small cellar windows sunk not more than 2 feet below the grade line, a semicircular area with a 9-inch brick wall will give the greatest durability for the least cost. If the area is 3 or 4 feet deep, and as many in length and width, the thickness of the wall should not be less than 12 inches for brick and 18 inches for stone.

Area walls should be coped with stone flagging, set in cement, the edge of the flagging projecting 1 inch over the face of the wall. If flagging cannot be obtained without excessive expense the top of the wall should be covered with 1 to 1 Portland cement mortar, about $\frac{3}{4}$ inch thick. Freestones and all porous stones are unsuited for area or fence copings.

Drainage.—The bottom of the area should be carried at least 6 inches below the window sill and should be formed of stone flagging or of brick laid in cement. Beneath the bottom of the area a small

cesspool or sand-trap (say 8 inches square) should be built, which should be connected by a 3-inch drain pipe with the main drain. A cast iron strainer or drain plate should be set over the cesspool, flush with or a little below the paving, so that it can be readily removed and the cesspool cleaned. The footings of the area walls should be started as deep as the bottom of the cesspool, both being below the frost line.

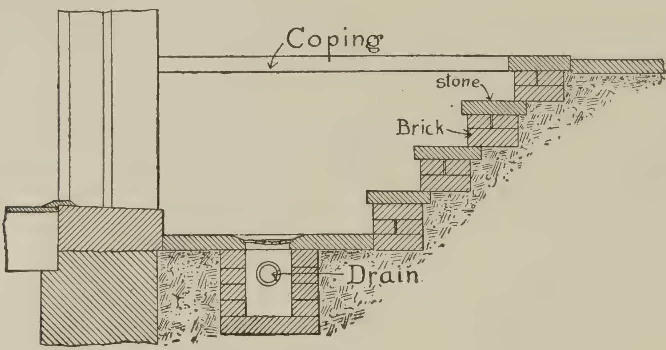


Fig. 49.

91. Entrance Areas.—All area steps, when practicable, should be of stone, or of stone and brick combined.* When the soil is hard and compact and not subject to heaving by frost, a small set of steps may be economically built by shaping the earth to the rake of the steps and building the steps directly on the earth, laying two courses of brick, in cement, for the risers, and covering with 2-inch stone treads, as shown

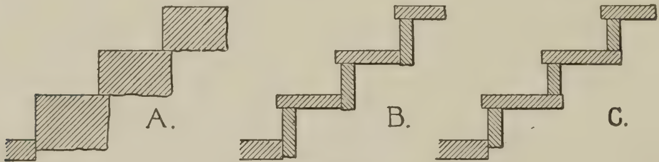


Fig. 50.

in Fig. 49. All parts of the steps should be set in cement, and well pointed, and the ends of the treads should be built into the side walls.

If the area is 6 feet or more in depth, or if the soil is sandy or a wet clay, then the area must be excavated beneath the steps and entirely surrounded by a wall. The steps may be formed of 2-inch stone risers and treads, or of solid stone, the ends in either case being supported by the side walls. If of solid stone the front of each step

* Or of concrete and twisted iron. (See page 369a)

should rest on the back of the stone below it, as shown at *A*, Fig. 50. If built of treads and risers they may be arranged either as shown at *B* or *C*. The arrangement shown at *B* is the strongest.

If the steps are more than 5 feet long a bearing wall or iron string should be built under the middle of the steps.

Stone steps should always be pitched forward about $\frac{1}{8}$ of an inch in the width of the tread.

In many localities plank steps, supported on plank strings, will last for a long time if the ground is excavated below them and the area walled up all around, and when they decay it is a small matter to replace them.

The platform at the bottom of the steps should be of stone or brick, set at least 4 inches below the sill of the door giving entrance to the building, and should be provided with cesspool, plate and drain, as described in Section 90.

All outside stone steps, fence coping, etc., should be set on a foundation carried at least 2 feet below grade, and in localities affected by frost below the freezing line.

92. **Vaults** are often built under entrance steps and porches, the walls of the vault forming the foundation for the steps and platform. The roof of the vault is generally formed of a brick arch or vault, two rowlocks in thickness, with the stone steps set in cement mortar on top of the arch.

Vaults under sidewalks may either be arched over with brick, the top of the arch leveled off with sand, cinders or concrete, and the sidewalk laid thereon, or the sidewalk itself, if of large stone flags, may be made to form the roof of the vault. In the latter case the joints of the stone slabs are closely fitted and often rebated, then caulked with oakum to within about 2 inches of the top and the remaining space filled with hot asphalt or asphaltic mastic. This will make a tight job for a time, but in the course of two or three years the joints will need to be cleaned out and refilled.

Any form of fireproof floor construction may also be used for covering sidewalk vaults and a cement sidewalk finished on top of it. This probably makes the best walk and the most durable construction, with a comparative slight thickness.

In San Francisco it is very common to build the sidewalks of cement, with steel tension bars or cables imbedded in the bottom, so that the same construction answers both for the walk and for covering the vault.

If brick arches, covered with sand, and a stone or brick pavement are used, the top of the arch should be coated with hot asphalt.

PAVEMENTS.

93. Although these do not come under the heading of foundations, they are more nearly related to that class of work than to any other, and may therefore be described here.

Pavements may be made either of thin slabs of stone, called flagging, of concrete, finished with Portland cement, or of hard bricks made especially for the purpose.

When large slabs of stone can be economically obtained, they make, in the long run, the most economical pavement, and one that is about as satisfactory as any.

A smoother pavement may be made with cement, and one that will be practically imperishable, but should there ever be occasion to cut through the pavement, or to change the grade, the cement and concrete must be destroyed, while the stone flagging can be taken up and relaid, either in the same place or used somewhere else. A stone sidewalk can also be repaired easier than either of the others.

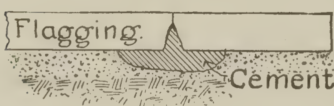


Fig. 51.

Stone Pavements.—As a rule only stones that split with comparatively smooth and parallel surfaces can be economically used for pavements, for, if the surface of the stone has to be dressed, it will generally be more economical to use concrete and cement or hard bricks.

For yards and areas, flagging from $2\frac{1}{2}$ to 3 inches thick is commonly used, the edges of the stones being trimmed so that the stones will be perfectly rectangular, and the joints between them straight and from $\frac{1}{8}$ to $\frac{3}{8}$ inch in width.

The stones should be laid on a bed of sand not less than 2 inches thick, and the edges should be bedded in cement, as shown in Fig. 51, the cement extending some 3 or 4 inches under the stone. On completion the joints should be thoroughly filled with 1 to 1 cement and fine sand, and struck smooth with the trowel.

In localities where the soil is dry and not affected by frost, as in Colorado, New Mexico, etc., the cement is generally omitted entirely, the stones being simply bedded in sand and the joints filled with fine sand.

This answers very well in those localities, but after a time grass and weeds commence to spring up through the joints in yards and

private walks, so that for first-class work bedding in cement should be specified.

Stone sidewalks are generally laid on a bed of sand, with the joints in the better class of work bedded in cement. The stones, when 5 feet long, should be at least 3 inches thick, and if 8 feet long, 5 or 6 inches thick. The best sidewalks are laid in one course, unless exceptionally wide.

In localities where the ground is affected by frost, as it is in most of the Northern States, the stones, if merely laid on a bed of sand, are sure to become displaced and out of level within one or two years. To prevent this, flagging stones, in front of business buildings at least, should have a solid support at each end.

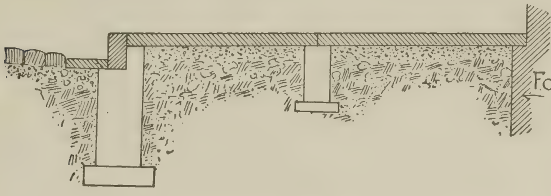


Fig. 52.

Fig. 52 shows the manner in which this is generally provided, and also the way in which the curb and gutter is supported. The curbstone should be at least 4 inches thick, and on business streets 6 inches.

The dwarf wall should be about 14 or 16 inches thick and carried below the frost line.

If the sidewalk is laid in two courses a slight wall of brick or stone should also be built under the middle of the walk to support the butting ends of the stones.

94. **Cement Walks.**—Cement sidewalks are extensively laid in the Western States, even in localities where excellent flagging stone is abundant and cement rather dear.

The cement walks are preferred on account of the smooth and even surface which they give. When properly laid they are also very durable. Cement walks, however, should only be laid where there is no danger of the grade being altered, and after the ground has become thoroughly settled and consolidated.

The durability of the walk depends principally upon the thickness of the concrete and the quality of the cement.

Only the best Portland cement should be used for the finishing,

although natural cements are sometimes used for the concrete. Portland cement throughout, however, is to be preferred.

For first-class work cement walks should be laid as follows:

The ground should be leveled off about 10 inches below the finished grade of the walk and well settled by tamping or rolling. On top of this a foundation 5 inches thick should be laid of coarse gravel, stone chips, sand or ashes, well tamped or rolled with a heavy roller. The concrete should then be prepared by thoroughly mixing 1 part of cement to 1 part of sand and 3 of gravel, in the dry state, then adding sufficient water from a sprinkler to make a dry mortar. The concrete should be spread in a layer from 3 to 4 inches thick, commencing at one end, and should be thoroughly tamped. Before the concrete has commenced to set the top or finishing coat should be applied, and only as much concrete should be laid at a time as can be covered that day. If the concrete gets dry on top the finishing coat will not adhere to it. The top coat should be prepared by mixing 1 part of high grade Portland cement with 1 part of fine sand, or 1 part clean, sharp, crushed granite (the latter is the best). The materials should be thoroughly mixed dry, and water then added to give the consistency of plastic mortar. It should be applied with a trowel to a thickness of 1 inch and carefully smoothed and leveled on top between straight-edges laid as guides. Used in the above proportion, one barrel of Portland cement will cover about 40 square feet of concrete. After the walk is finished it should be covered with straw to prevent it drying too quickly.

For brick paving see Section 381.

SHORING, NEEDLING AND UNDERPINNING.

95. The direction of these operations when required is generally left to the contractor, as the responsibility for the successful carrying out of the work devolves upon him.

The architect will be wise, however, when such operations are being done in connection with work let from his office, to see that proper precautions are taken for safety, and that all beams or posts have ample strength for the loads they have to support. When heavy or difficult work has to be done, it should, if possible, be intrusted to some careful person who has had experience in that class of work, as it is almost a trade by itself.

Shoring is supporting the walls of a building by inclined posts or struts, generally from the outside, while its foundations are being car-

ried down, or while the lower portion of the wall is being removed and girders and posts substituted.

The usual method of shoring the walls of buildings not exceeding three stories in height, especially when done for the purpose of holding up the walls while being underpinned, is shown in Fig. 53.

The props or shores are inserted in sockets cut in the wall, with their lower ends resting on a timber crib supported on the ground. At least two sets of shores should be used, one to support the wall as low down as possible and the other as high up as possible. The latter shores should not have a spread at the bottom of more than one-third of their height. The platform should be made large enough so as not to bring too great a pressure on the ground, and the shores should be driven into place by oak or steel wedges.

The shores should be spaced according to the height and thickness of the wall, and all piers and chimneys should be shored. Generally a spacing of 6 feet between the shores will answer.

Only a part of the foundation should be removed at a time, and as soon as three sets of shores are in place the wall should be underpinned, as described in Section 97. As fast as the wall is underpinned the first set of shores should be moved along, always keeping two sets in place, and working under or with one set.

Shoring may often be successfully employed for holding up the corner of a building while a pier or column is being changed, and sometimes when the lower part of the wall is to be removed and a girder slipped under the upper portion. In the latter case, however, *needling* is generally more successful and attended with less risk.

96. Needling is supporting a wall, already built, on transverse beams or needles placed through holes cut in the wall and supported at each end either by posts, jackscrews or grillage. At least one end of the horizontal beam should be supported by a jackscrew.

Wherever a long stretch of wall is to be built up at one time, and there is working space on each side of it, needling should be employed.

The beams must be spaced near enough together so that the wall will not crack between them, and the size of the beams carefully proportioned to the weight of the wall, floors, etc. In very heavy buildings steel beams should be used for the needles, and they should be spaced not more than 2 feet apart. In three or four-story buildings the needles may be of large timber and spaced from 4 to 6 feet apart. Each chimney or pier should have one or more needles directly under it.

When the first story walls or supports are to be removed, the beams or needles are usually supported on long timbers having a screw under the lower end; or, if the wall is very high or thick, a grillage of timber is built up and the jackscrews are placed on top of the grillage, the ends of the needles resting on a short beam supported by two screws, in the manner shown in Fig. 54.

When it is desired to remove the first story wall of a building for the purpose of substituting posts and girders, or for rebuilding the wall, holes should be cut in the wall from 4 to 6 feet apart, according to the weight to be supported and the quality of the brick or stone work, and at such a height that when the needles are in place they will come a few inches above the top of the intended girder. Solid supports should then be provided for the uprights, the needles put through the wall, and posts, having screws in the lower ends, set under them, the base of the screws resting on the solid support previously provided. If the needles do not have an even bearing under the wall, iron or oak wedges should be driven in until all parts of the wall bear evenly on the needles. The jacks should then be screwed up until the wall is entirely supported by the needles, care being taken, however, not to raise the wall after the weight is on the needles.

The wall below may then be removed, the girder and posts put in place, and the space between the girder and the bottom of the wall built up with brickwork, the last course of brick or stone being made to fit tightly under the old work. The needles may then be withdrawn and the holes filled up.

97. **Underpinning** is carrying down the foundations of an existing building, or, in other words, putting a new foundation under the old ones.

New footings may generally be put under a one or two-story building resting on firm soil without shoring or supporting the walls above, the common practice being to excavate a space only 2 to 4 feet long under the wall at a time, sliding in the new footing and wedging up with stone, slate, or steel wedges.

Where the underpinning is to be 3 feet high or more, or where the building is several stories in height, the walls should be braced or supported by shores or needles.

The usual method of underpinning the walls of buildings where a cellar is to be excavated on the adjoining lot is shown in Fig. 53.

Pits should first be dug to the depth of the new footing, and a timber platform built as shown; the shores should then be put in place and wedged up with oak wedges.

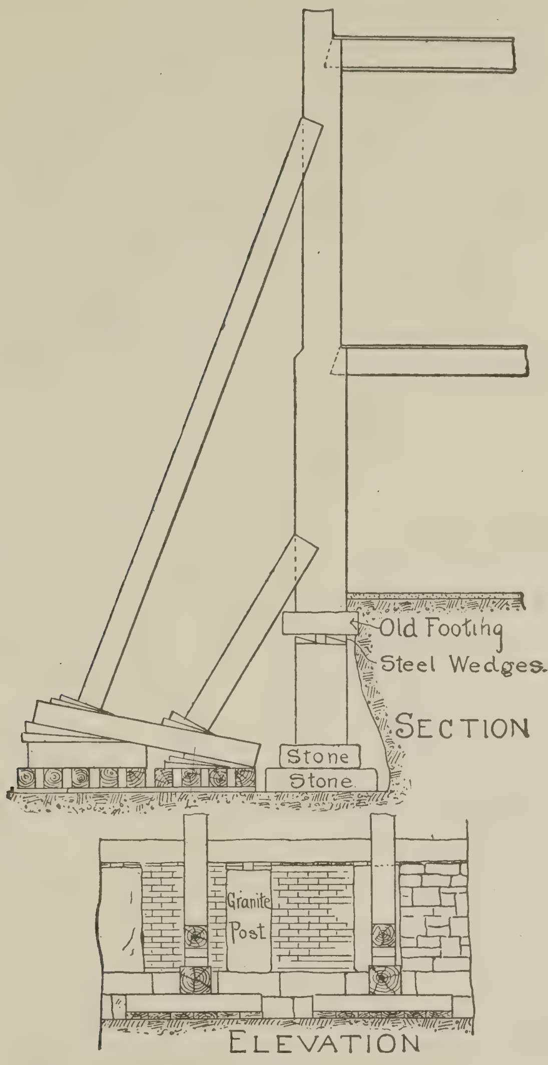


Fig. 53.

Sections about 3 feet wide between the shores should then be excavated under the wall, new footing stones laid, and the space between the new and old footings filled with brick or stone work. Where the height between the new and old footings does not exceed 5 feet, granite posts, if available, offer special advantages for underpinning.

They should be from 12 to 18 inches wide on the face and of a thickness equal to that of the wall; they should be cut so as just to fit between the new and old work, and with top and bottom surfaces dressed square; they should be set in a full bed of Portland cement mortar, and the top joint also filled with mortar and brought to a bearing with steel wedges.

If granite posts are not available good flat stone or hard brick laid in cement mortar may be used instead, wedging up under the old wall with pieces of slate driven into the upper bed of cement, or with steel wedges. Under heavy walls the latter only should be used. If the bottom of the old footings is of soft brickwork, pieces of hard flag-

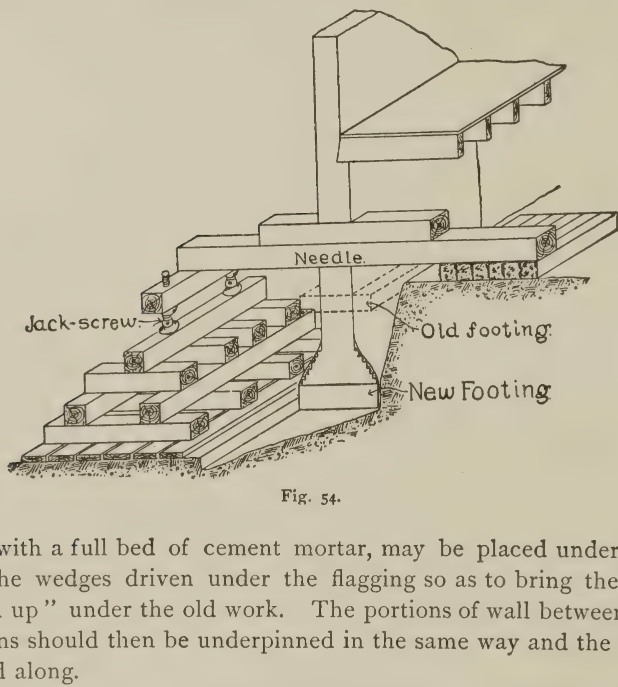


Fig. 54.

ging, with a full bed of cement mortar, may be placed under them, and the wedges driven under the flagging so as to bring the latter "hard up" under the old work. The portions of wall between these sections should then be underpinned in the same way and the shores moved along.

Where granite posts are used they may be placed 3 feet apart and the space between built up with flat rubble or hard brick, wedged up under the old wall with slate.

If the soil under the old building is sufficiently firm, so that it will not cave or "run away," and there is working space beneath the lower floor, the ground may be leveled off, a platform of plank and timbers placed on top of it, and needles used for supporting the wall,

as shown in Fig. 54. Where needles are used all of the underpinning under the portion of wall supported may be put in at the same time.

The underpinning should be done as quickly as possible after the shores or needles are in place, so as not to require their support for a longer time than necessary. The needles or shores should, however, not be removed until the cement has had time to set.

98. Chicago Practice.

In building the modern tall office building in Chicago the foundations generally have to go below those of the adjacent buildings, and, the ground being compressible, new party wall foundations are almost invariably required. The consequence is that the old walls have to be supported while the new foundation is being put under them. This is usually done by means of steel needles placed from 12 to 24

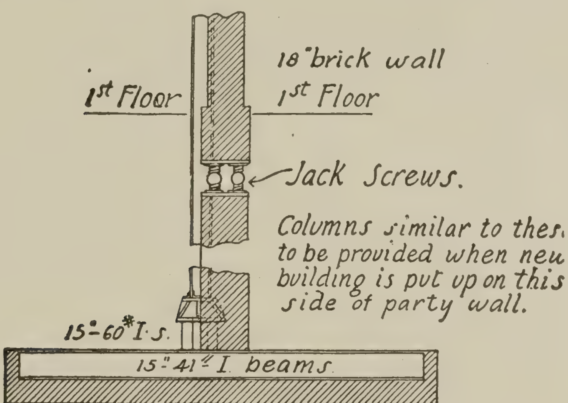


Fig. 55.

inches apart, their ends resting on long beams placed parallel with the wall and supported by jackscrews. Very often an entire wall is supported in this way, several hundred jackscrews being required for the purpose.

In erecting buildings of skeleton construction it is often impracticable to remove the old wall, and the new building is supported by iron columns placed against the wall and resting on a new foundation put in under the old one. In building the New York Life Building in Chicago such was the case, and the adjacent wall was held up by jackscrews, as shown in Fig. 55, which were inserted to keep the wall in place during the settlement of the new work. As the new foundations settled the jacks were screwed up, so as to keep the old wall in its original position. In this case the jacks were left in place.

99. Bracing.—Where buildings have been built with a party wall, and one of the buildings is torn down, leaving the adjacent

walls unsupported, they should be protected from falling by spreading braces or inclined shores, according to special conditions.

Where there is a building on the other side of the vacant lot, and within 40 or 50 feet, the walls of both buildings may be best supported by spreading braces, after the manner shown in Fig. 56.

If the distance between the buildings does not exceed 25 feet, the braces may be arranged as shown at *A* or *B*. If more than 25 feet, the braces must be trussed in a manner similar to that shown at *C*.

[Iron or steel rods are preferable for the vertical ties, as they can be screwed up, and any sagging caused by shrinkage in the joints overcome.]

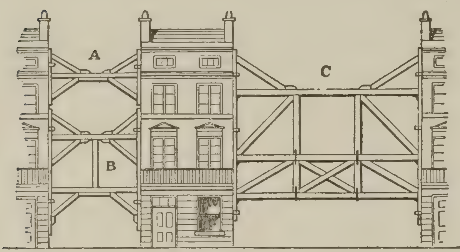


Fig. 56.

If the buildings are very high every other story should be braced. The ends of the braces or trusses must be supported vertically, so that they will not slip down. Where there are offsets in the wall these may serve for a vertical support ; if there are no offsets, then the braces should be supported by vertical posts, starting from the foundation, or sockets might be cut in the wall and corbels let in and bolted through from the inside.

A truss should be placed opposite the fronts, and should be proportioned so as to resist the thrust from any arches there may be in the front. The braces should be about 8x8 or 10x10 inches in size, with 6x12 uprights against the wall, the ends of the braces being mortised into the uprights.

If there is no wall opposite the building to be braced, then inclined braces must be used, arranged in a similar manner to the shores shown in Fig. 53, only with a greater inclination. The ends of the braces should be brought to a bearing by oak wedges.

Chapter IV.

LIMES, CEMENTS AND MORTARS.

There is hardly any material used by the architect or builder upon which so much depends as upon mortar in its different forms, and it is important that the architect should be sufficiently familiar with the different kinds of limes and cements to know their properties and in what kind of work each should be used. He should also be able to judge of the quality of the materials with sufficient accuracy to prevent any that is actually worthless from being used, and should have some knowledge of mortar mixing.

100. Lime.—Common lime, sometimes called quicklime or caustic lime, is produced by the calcination (or heating to redness) of limestones of varying composition. This is done by burning the stone in a kiln with an oviod vertical section and circular horizontal section. The broken stone and fuel (generally coal) are put in in layers, the fire lighted at the bottom, and as the lime drops to the bottom new layers of stone and coal are put in at the top, so that the kiln may be kept burning for weeks at a time. The limestones from which limes and cements are produced differ greatly in their composition, ranging from pure carbonate of lime, such as white chalk or marble, to stones containing 10 per cent. or more of impurities, such as silica, alumina (clay), magnesia, oxide of manganese and traces of the alkalies. The quality of the lime will consequently depend much upon the percentage of impurities contained in the stone from which it is made. Lime is manufactured in nearly every State in the Union, each locality generally producing its own supply.

There is considerable difference, however, in the limes of different localities, and before using a new lime the architect should make careful inquiries regarding its quality, and if it has not been much used it would be better to procure a lime of known quality, at least for plastering purposes; for common mortar it is not necessary to be so particular.

In most parts of New England lime is sold by the barrel, but in many parts of the country it is sold in bulk, either by the bushel or by weight.

101. Characteristics of Good Lime.—Good lime should possess the following characteristics: 1. Freedom from cinders and clinkers, with not more than 10 per cent. of other impurities. 2. It should be in hard lumps, with but little dust. 3. It should slake readily in water, forming a very fine, smooth paste, without any residue. 4. It should dissolve in soft water.

There are some limes which leave a residue consisting of small stones and silica and alumina in the mortar box, after the lime is drained off. Such limes may answer for making mortar for building purposes, but should not be used for plastering if a better quality of lime can be procured.

102. Slaking and Making into Mortar.—The first step in the manufacture of lime mortar consists in the *slaking* of the lime. This is generally done by putting the lime in a water-tight box and adding water either through a hose or by pails, the amount of water depending upon the quality of the lime. Lime such as is sold in New England requires a volume of water equal to two and one-half to three times the volume of the lime. The water is rapidly absorbed by the lime, causing a great elevation of temperature, the evolution of hot and slightly caustic vapor, and the bursting of the lime into pieces, and finally the lime is reduced to a powder, the volume of which is from two and a half to three and a half times the volume of the original lime. In this condition the lime is said to be slaked and is ready for making into mortar. The Thomaston and Rockland (Maine) lime, as also most other limes sold in New England, slake without leaving a residue, and the mortar is made by mixing clean, sharp sand with the slaked lime in the proportion of 1 part of lime to about 5 of sand by volume. Practically the proportion of sand is seldom, if ever, measured, but the sand is added till the person mixing the mortar thinks it is of the proper proportion. For brickwork over a certain proportion of sand cannot well be added, for if there is too much sand in the mortar it will stick to the trowel and will not work easily. With stonework the temptation is always to add too much sand, as sand is generally *cheaper* than lime. The architect or superintendent should take pains to make himself familiar with the appearance of good mortar, so that he can readily tell at a glance if it has too much sand. Mortar that contains a large proportion of lime is said to be *rich;* if it has a large proportion of sand and works hard it is said to be *stiff*, and to make it work more readily it is *tempered* by the addition of water. Tempered mortar looks much richer than stiff mortar, though it may not be so. If the mortar slides readily

from the trowel it is of good quality, but if the mortar sticks to the trowel there is too much sand in proportion to the lime. The color of the mortar depends much upon the kind and color of the sand used.

Many of the limes used in the Western States when slaked leave a residue of stones, lumps and gravel, so that instead of mixing the mortar in the same box in which the lime is slaked, a larger proportion of water is added, and the slaked lime and water (about as thick as cream) is run off through a fine sieve into another box, in which the mortar is mixed. Such lime does not make as good mortar as that which leaves no impurities, but it does very well for use in brick and stone work.

The general custom in making lime mortar is to mix the sand with the lime as soon as the latter is slaked and letting it stand until required for use. Much stronger and better mortar would be obtained, however, if the sand were not mixed with the slaked lime until the mortar was needed.

103. **Sand.**—The sand used in making mortar should be angular in form, of various sizes, and absolutely free from all dust, loam, clay or earthy matter, and also from large stones. It is generally necessary to pass the sand through a screen to insure the proper degree of fineness. For rough stonework a combination of coarse and fine sand makes the strongest mortar. For pressed brickwork it is necessary to use very fine sand. The architect or superintendent should carefully inspect the sand furnished for the mortar, and if he has any doubts of its cleanliness, a handful put in a tumbler will at once settle the question, as the dirt will separate and rise to the top. Another simple method of testing sand is to squeeze some of the moist sand in the hand, and, if upon opening the hand the sand is found to retain its shape, it must contain loam or clay, but if it falls down loosely it may be considered as clean. Sand containing loam or clay should be at once rejected and ordered from the premises. As a rule, it is better that the sand should be too coarse rather than too fine, as the coarse sand takes more lime and makes the strongest mortar. Some unscrupulous masons may attempt to use fine sandy loam in their mortar, as it takes the place of lime in making the mortar work easily ; but, of course, it correspondingly weakens the mortar, and its use should never be permitted.

104. **White and Colored Mortars.**—White and colored mortars to be used in laying face brick should be made from *lime putty* and finely screened sand. After the slaked lime has stood for several

days the water evaporates and the lime thickens into a heavy paste, much like putty, and from which it takes its name of lime putty. By the time the putty is formed the lime is sure to be well slaked and will not then swell or "pop." Colored mortar is made by the addition of mineral colors to the white mortars. Colored mortar should *never* be made with *freshly slaked lime*, but only with lime putty at least three days old. For Mortar Colors see Section 148.

Common lime when slaked and evaporated to a paste may be kept for an indefinite time in that condition without deterioration, if protected from contact with the air so that it will not dry up. It is customary to keep the lime paste in casks or in the boxes in which it was slaked, covered over with sand, to be subsequently mixed with it in making the mortar. Clear lime putty may be kept for a long time in casks, for use in making colored mortar, only a little mortar being made up at a time.

105. Setting.—Lime paste or mortar does not set like cement, but gradually absorbs carbonic acid from the air and becomes in time very hard; the process, however, requires from six months to several years, according to the thickness of the mortar and its exposure to the atmosphere. If permitted to *dry* too quickly it never attains its proper strength. If frozen, the process of setting is delayed and the mortar is much injured thereby. Alternate freezing and thawing will entirely destroy the strength of the mortar. Lime mortar will not harden under water, nor in continuously damp places, nor when excluded from contact with the air.

106. Preserving.—Fresh burned lime will readily absorb moisture from a damp atmosphere, and will in time become slaked thereby losing all of its valuable qualities for making mortar. It is therefore important that great care should be taken to secure freshly burned lime and to protect it from dampness until it can be used. If the lime is purchased in casks it should be kept in a dry shed or protected by canvas, and if it is bought in bulk it should be kept in a water-tight box built for the purpose.

On no account should the superintendent permit of the use of air-slaked lime, as it is impossible to make good mortar of it.

107. Durability of Lime Mortar.—Good lime mortar, when protected from moisture, has sufficient strength for all ordinary brickwork, except when heavily loaded, as in piers, and continues to grow harder and stronger every year. The writer has often seen instances in old walls where the lime mortar was as strong as the

bricks, and where the adhesion of the mortar to the bricks was greater than the cohesion of the particles of the bricks.

A specimen of mortar, supposed to be the most ancient in existence, obtained from a buried temple on the island of Cyprus, was found to be hard and firm, and upon analysis appeared to be made of a mixture of burnt lime, sharp sand and gravel, some of the fragments being about ½ inch in diameter. The lime was almost completely carbonized.*

Lime mortar, however, attains its strength slowly, and where high buildings are built rapidly the mortar in the lower story does not have time to get sufficiently hard to sustain the weight of the upper stories, and for such work natural cement should be added to the lime mortar.

HYDRAULIC LIME.

108. Hydraulic limes are those containing, after burning, enough lime to develop, more or less, the slaking action, together with sufficient of such foreign constituents as combine chemically with lime and water, to confer an appreciable power of *setting* under water, and without access of air.

The process of *setting* is entirely different from that of drying, which is produced simply by the evaporation of the water. Setting is a chemical action which takes place between the water, lime and other constituents, causing the paste to harden even when under water.

Hydraulic lime or cement should not be used after it has commenced to set, as the setting will not take place a second time and the strength of the mortar will be lost.

In the great majority of natural hydraulic limes commonly used for making mortar, the constituent which confers hydraulicity is *clay*, although silica also has the same effect.

Hydraulic limes containing clay may be arranged in three classes, according to their amount of hydraulic energy:

1. "*Feebly hydraulic*—containing 10 to 20 per cent. of impurities. This slakes in a few minutes, with crackling, heat and emission of vapor. If made into a paste and immersed in water in small cakes, it will harden so as to resist crushing between the thumb and finger in from twelve to fifteen days.

2. "*Ordinary hydraulic*—containing 17 to 24 per cent. of impurities. Slakes after an hour or two, with slight heat and fumes, without crackling. Sets under water in six or eight days.

* William Wallace, Ph.D., F. R. S E., in London *Chemical News*, No. 281.

3. "*Eminently hydraulic*—containing at least 20 per cent of impurities. Slakes very slowly and with great difficulty, with slight heat. Sets under water in twelve to twenty hours and becomes hard in two to four days." *

Artificial hydraulic lime can be manufactured by mixing together, in proper proportions, thoroughly slaked common lime and unburnt clay, then burning and grinding in much the same manner as in the manufacture of Portland cement; but as the process of manufacture is nearly as expensive as for making Portland cement, it is more profitable to make cement, on account of its superior hydraulic energy.

No hydraulic lime is manufactured, artificially, in the United States, and but very few hydraulic limes are in use.

A gray lime is obtained at Morrison and a few other locations in Colorado which hardens under water and makes very strong mortar. It is also sometimes used for making concrete.

A very simple experiment will determine if a lime is hydraulic or not: Make a small cake of the lime paste, and after it has commenced to stiffen in the air, place it in a dish of water so that it will be entirely immersed. If it possesses hydraulic properties it will gradually harden, but if it is not hydraulic it will soften and dissolve.

Hydraulic lime mortar is made in the same way as common lime mortar, care being taken to use sufficient paste to coat all grains of sand and to fill up the voids between them.

109. Pozzuolanas is a name given to certain clayey earths containing 80 to 90 per cent. of clay, with a little lime and small quantities of magnesia, potash, soda, oxide of iron, or manganese.

When finely powdered in their raw state and added to lime mortar they confer hydraulic properties to a considerable degree.

Natural Pozzuolana is a naturally-burnt earth of volcanic origin found at Pozzuoli, near Vesuvius, and in the caverns of St. Paul, near Rome. It is found in the form of powder, and when sifted is used all along the Mediterranean coast for making hydraulic mortars.

Béton (similar to concrete) as prepared in that region is generally made of Pozzuolana, lime and aggregates in the following proportions:

Pozzuolana	12	parts.
Sand	6	"
Good quicklime	9	"
Small stones	13	"
Ground slag	3	"

* Ira O. Baker in "Masonry Construction."

Pozzuolana is not used in this country, but as the name is frequently found in books on masonry construction, it is well for the young architect to know what it is.

Brick dust, mixed with common lime, produces a feebly hydraulic mortar, and adds materially to its strength.

HYDRAULIC CEMENTS.

Hydraulic cements are made by calcining limestones containing from 30 to 60 per cent. of clay.

They do not slake or break up like lime, and their paste sets very quickly, either in air or water.

They may be divided into two classes:

1. Natural cements.
2. Artificial cements.

110. Natural Cements are made from a natural rock, of which the principal ingredients are carbonate of lime, carbonate of magnesia and clay. The stone, after being quarried, is broken into pieces of a suitable size and mixed with anthracite coal and burned in kilns specially constructed for the purpose. Great care is required in selecting and preparing the stone for the kiln and in burning it to a consistent degree of calcination.

After calcining the material is drawn out of the kilns and carefully inspected. That which is properly burned is sent to the mill to be finely ground between ordinary millstones, and the underburned or over-calcined thrown away.

Natural cements weigh about two-thirds as much as Portland cement, are very quick setting and have less ultimate strength. They attain their full strength, however, sooner than the Portland cements, and are sufficiently strong for all ordinary building operations.

They have been used in many of the largest building and engineering works in this country with perfectly satisfactory results, and their use is extending every year.

They are sold at a less price than Portland cements, and in localities where the cost of transportation is not excessive are almost exclusively used for cement mortar.

111. Distribution of Natural Cements.—"In no other country in the world is there to be found cement rock formations which are at all to be compared with those so well distributed throughout the United States. . . . Here we have immense beds of cement rock absolutely free from any extraneous substances, perfectly pure

and clean, with layer upon layer, extending for thousands of feet without appreciable variation in the proportion of the ingredients."*

Natural cements are manufactured in very many localities throughout this country, the cement being commonly known by the name of the place from which the stone is obtained, although, as there are often several manufactories in the same locality, there may be several brands of cement made from the same rock. The difference in the quality of such brands is generally due to the care exercised in their manufacture.

The localities in which natural cements are made on an extensive scale are as follows:

Rosendale, N. Y.—Natural cement was first made in this country in the town of Rosendale, Ulster County, N. Y., during the year 1823, for use in building the Delaware and Hudson Canal. Since then inexhaustible deposits have been found of the fine-grained natural stone out of which Rosendale cement is made, and there are several companies which manufacture cement from this rock, each having a special brand for their product. Owing to the length of time for which they have been used, and the special advantages enjoyed for transportation and nearness to the great building centres of the country, Rosendale cement is more widely known than any other of the natural cements. It is generally of a very good quality and well suited for building operations.

Very good natural rock cements are also made at Buffalo, Akron and Howe's Cave, N. Y.

Louisville, Ky.—Louisville cement, made from natural rock quarried at this place, is probably the leading natural cement beyond the Alleghenies, the product being exceeded only by the production from the Rosendale district. There are several brands of this cement in the market, and they find their way as far west as the Rocky Mountains.

At *Utica, Ill.*, a natural cement has been manufactured since 1838. This cement has always stood well in public favor, and is largely used throughout the West.

At *La Salle, Ill.*, a natural cement is manufactured from the same rock formation as that running through Utica, Ill.

The *Milwaukee Cement Co.* manufactures a natural cement from rock obtained near Milwaukee, Wis., which is extensively used.

Mankato, Minn.—A cement rock of the very best quality exists at this place, and the manufactured product has obtained a strong foothold in the markets of the Northwest.

Cement, Ga.—The cement manufactured from stone quarried at this place "probably has no superior in this country. Used as an exterior plaster on a house in Charleston in 1852, the stucco still remains unimpaired, while the sandstone lintels over the windows have long since been worn away."

Fort Scott, Kan.—A natural cement has been manufactured at this place since 1867. The product resembles that of Cement, Ga.

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* Uriah Cummings in the *Brickbuilder*.

Natural cements are also manufactured at Siegfried's Bridge, Lehigh Valley, Pa.; Balcony Falls, Va., and Cumberland, Md., and to a limited extent at several localities in the West.

[An extended description of the natural cements manufactured in this country is given in a series of articles by Uriah Cummings in the *Brickbuilder* for 1895.]

112. Analysis of Natural Cements.—The following table, giving the chemical constituents of the leading natural cements, will be found useful in comparing the products from different localities:

TABLE VII.—TABLE OF ANALYSIS—NATURAL ROCK CEMENTS.

NUMBER.	SILICA.	ALUMINA.	IRON OXIDE.	LIME.	MAGNESIA.	POTASH AND SODA.	CARBONIC ACID, WATER.
1	24.30	2.61	6.20	39.45	6.16	5.30	15.23
2	34.66	5.10	1.00	30.24	18.00	6.16	4.84
3	23.16	6.33	1.71	36.08	20.38	5.27	7.07
4	26.40	6.28	1.00	45.22	9.00	4.24	7.86
5	25.28	7.85	1.43	44.65	9.50	4.25	7.04
6	30.84	7.75	2.11	34.49	17.77	4.00	3.04
7	27.30	7.14	1.80	35.98	18.00	6.80	2.98
8	28.38	11.71	2.29	43.97	2.21	9.00	2.44
9	27.69	8.64	2.00	42.12	14.55	2.00	3.00
10	24.34	8.56	2.08	61.62	0.40	2.00	0.80
11	23.32	6.99	5.97	53.96	7.76	....	2.00
12	27.60	10.60	0.80	33.04	7.26	7.42	2.00
13	33.42	10.04	6.00	32.79	9.59	0.50	7.66
14	22.58	7.23	3.35	48.18	15.00	....	3.66
15	26.61	10.64	3.50	42.12	13.12	2.00	2.01
16	25.15	8.00	3.28	49.53	13.78	....	0.26

REFERENCE:

1. Buffalo Hydraulic Cement, Buffalo, N. Y.
2. Utica Hydraulic Cement, Utica, Ill.
3. Milwaukee Hydraulic Cement, Milwaukee, Wis.
4. Louisville Hydraulic Cement, "Fern Leaf," Louisville, Ky.
5. Louisville Hydraulic Cement, "Hulme," Louisville, Ky.
6. Rosendale Hydraulic Cement, "N. Y. & R.," Rosendale, N. Y.
7. Rosendale Hydraulic Cement, "Hoffman," Rosendale, N. Y.
8. Cumberland Hydraulic Cement, Cumberland, Md.
9. Akron Hydraulic Cement, "Cummings," Akron, N. Y.
10. California Hydraulic Cement, South Riverside, Cal.
11. Fort Scott Hydraulic Cement, "Brockett," Kansas City, Mo.
12. Utica Hydraulic Cement, La Salle, Ill.
13. Shepherdstown Hydraulic Cement, Shepherdstown, Va.
14. Howard Hydraulic Cement, Cement, Ga.
15. Mankato Hydraulic Cement, Mankato, Minn.
16. James River Hydraulic Cement, Balcony Falls, Va.

113. Characteristics of Natural Cement.—*Color.*—The color of the natural cements used in this country vary with the locality in which they are found. Most of the cements mentioned in Section 111 are brown in color, in light or dark shades. "In Rosendale cement a light color generally indicates an inferior, underburnt rock.

"The *weight* of good Rosendale cement varies from 49 to 56 pounds per cubic foot, or 60 to 70 pounds per bushel, according to its fineness and the density of packing. The harder-burned varieties are also heavier than those that are underburned. The weight per barrel of Ulster County Rosendale cement averages 300 pounds net; Akron, Milwaukee, Utica and Louisville cements weigh 265 pounds per barrel net."

Testing Rosendale Cement.—The value of cements for making mortar varies greatly with their physical properties, and since one lot is liable to differ very much from another lot of the same brand, it is very necessary to be able to test the character of any particular cement.

Brand.—Any particular brand of cement will generally average about the same strength and quality, and the architect should ascertain what brands of cement are giving the best satisfaction and specify those brands. For ordinary building purposes it will only be necessary for the superintendent to examine the casks to see that they bear the brand specified and to see that the cement has not been injured by dampness. If the cement is found to have become hard or crusty, it has absorbed moisture and should not be used in making the mortar.

If the superintendent has any doubts of the quality of the cement, let him take two handfuls of cement and mix with as little water as possible into two cakes; put one in water and leave the other in air. If the air cake dries of a light color without any particular well-defined cracks, and the water cake sets with a darker color and without cracks, the cement is probably good. If the cement cracks badly in setting, or if it becomes contorted (sometimes called blowing), it is positively poor and should be rejected.

Another simple test of the *soundness* of cement, which is the property of not expanding or contracting, or checking or cracking in setting, is to place some mortar in a glass tube (a swelled lamp chimney is excellent for this purpose) and pour water on top. If the tube breaks the cement is unfit for use in damp places. Any natural cements that give satisfactory results with these simple tests will answer for making mortar for any ordinary building construction.

Where great strength is required in the mortar it is better to use Portland cement, but if for any reason Portland cement cannot be obtained, or its price prohibits its use, then the strength of the natural cement should be carefully tested, in the manner described in Sections 117-123 for testing Portland cement.

Clear Rosendale cement one week old in water should have a tensile strength per square inch of at least 60 pounds, and the best brands should average 100 pounds.

Storing.—It is very essential that cements of all kinds should be stored in a dry place, where there is no danger of its absorbing moisture, until it can be used. A very little moisture will cause the cement to set, and any cement that has commenced to set should be rejected.

114. Roman Cement is made by calcining nodules found in the London clay. The color of the calcined stone is generally a rich brown.

Weight and Strength.—" Good Roman cement should not weigh more than 75 pounds per bushel, and should set very quickly (within about fifteen minutes of being gauged into paste)." A heavier cement than this is likely to be overburnt or else injured by the absorption of carbonic acid from the air.

Neat Roman cement seven days old in water should possess a tensile strength of from 50 to 80 pounds per square inch.

Storing.—Roman cement is sold in a ground state and is put up in casks, which must be kept carefully closed and dry, otherwise the cement will absorb carbonic acid and become inert.

Uses.—The strength of Roman cement diminishes rapidly when mixed with sand, and not more than 1 or 1½ parts of sand to 1 of cement should be used in mixing the mortar. Roman cement mortar should be mixed in very small quantities and used at once, and on no account beaten up again after the setting has commenced.

ARTIFICIAL CEMENTS.

115. Portland Cement.—The most useful of artificial cements is that known as Portland cement.

The first Portland cement was made by Joseph Aspdin, of Leeds, England, who obtained a patent on it, dated October 21, 1824. For making his cement he used powdered limestone and a certain quantity of clay, which he mixed together with water to a paste, then evaporated in pans. After evaporation the mixture was broken up into lumps, calcined at a high temperature and ground.

The name of Portland was given to the cement on account of the fact that when troweled to a smooth surface it resembled rubbed Portland stone, one of the chief building stones of England.

"Portland cement requires a homogeneous mixture containing in proper proportions carbonate of lime, alumina (clay), silica and iron. . . . This mixture must be subjected to a heat sufficiently high to produce a vitrified, dense and heavy clinker, and afterward ground to a fine powder."

The proper proportions of the above ingredients are rarely found in a natural stone, so that it is necessary to obtain the lime and alumina from separate sources and mix them in the proper proportions artificially.

At the present time the bulk of the English cement, and much of the German cement, is manufactured from chalk instead of the hard limestones. This chalk is mixed with clay in the proper proportions, before burning, in a large wash mill, and the slurry is then run off and dried, either by artificial means or sun evaporation. After drying the mixture is burned at a fixed temperature into a scoriaceous mass, resembling pumice stone, to which the name of "clinker" is applied. This "clinker" being dried, ground to powder and passed through sieves, furnishes the finished product.

The quality of the cement depends upon the quality of the raw materials, the proper proportion of the mixture, the degree to which it is burnt, the fineness to which it is ground, and constant and scientific supervision of all the details of manufacture.

116. American Portland Cement.—The first American Portland cement was manufactured by Mr. David O. Saylor in the year 1874 at Coplay, Pa. Since that time several factories have been established in the United States, and in the year 1894 there were nineteen factories, which made about 700,000 barrels; this amount, however, being but 18 per cent. of what was imported. Most of the American Portland cement is manufactured in the neighborhood of Coplay, Pa., the largest factory being that of the Atlas Cement Co., where 1,800 barrels a day are now manufactured. "All the factories located in this region make cement under the dry process from an argillaceous limestone. There are several factories in New York State, along the Erie Canal, and in Ohio, where marl and clay or limestone and clay are used. Practically nine-tenths of the Portland cement manufactured in this country is made in the States of Pennsylvania, New York and Ohio. Other States where small quantities are manufactured are Texas, Colorado, Dakota, Oregon, California and the Territory of Utah. There is plenty of raw material

* The output of this Company in 1901 was over 3,000,000 barrels

suitable for making the highest grade of Portland cement, in almost every State in the Union." *

Several of the American Portland cements have been shown by thousands of carefully conducted tests to be equal in quality to any of the imported cements, and they have been used with perfectly satisfactory results in many of the largest engineering works in this country, as well as many of our largest buildings. The Mississippi jetties were built with American Portland cement, and they have successfully withstood the most severe test to which cement concrete can be subjected.

Good Portland cement is slow-setting, as compared with the natural cements, but greatly surpasses them in ultimate strength.

"The induration, or 'setting,' of Portland cement consists in the formation of a real mineral of a crystalline rock species, analogous to natural zeolites."

Owing to the greater expense in manufacturing Portland cement, its market price is nearly three times that of the Rosendale cements, but where great strength is required, as in brick or stone piers, or for concrete footings, Portland cement should always be preferred to any of the natural cements.

117. Testing Portland Cement.—In all important engineering works it is customary to test every fifth or tenth cask of cement for its soundness, fineness and strength.

For use in building piers and footings for ordinary buildings, it will be sufficient if the superintendent sees that only brands bearing a good reputation are used and that none of the cement has commenced to set or crust in the casks. Any such cement should be rejected.

In places where great strength and durability is required of the mortar careful tests should be made of every lot of cement used, as one lot of cement may differ very much from another lot of the same brand.

118. Color.—Some idea of the quality of the cement may be gained from its color, but it should be supplemented by further tests for strength and fineness, as a bad cement may be of good color. Good Portland cement, as received from the manufacturers, should be of a gray or bluish gray color.

A brown or earthy color indicates an excess of clay and shows that the cement is inferior—likely to shrink and disintegrate. A coarse,

* William G. Hartranft, before the Master Builders' Exchange of Philadelphia.

bluish-gray powder is probably over-limed and likely to blow. An undue proportion of underburnt material is generally indicated by a yellowish shade.

Weight.—The weight of Portland cement is sometimes specified as one of the requirements to be fulfilled, but as it is never constant, and cannot be precisely determined, it is of very little service in determining the value of a cement.

The finer a cement is ground the more bulky it becomes, and, consequently, the less it weighs; a light-burned cement also weighs less than one that is harder burned, so that light weight may indicate either a desirable fine grinding or an objectionable underburning.

The weight of cement should be determined by sifting the cement into a measure with a fall of 3 feet and striking the top level with a straight-edge. The following values determined in this way give fair averages for ordinary cements:

Portland, English and German........	77 to 90 lbs.	per cubic foot.
Portland, fine ground French.........	69 "	"
Portland, American..................	95 "	"
Roman............................	54 "	"
Rosendale.........................	49 to 56 "	"

A bushel contains practically $1\frac{1}{4}$ cubic feet, so that the weight per bushel can be easily computed from the above table, if desired.

119. Activity.—A mortar is said to have *set* when it has attained such a degree of hardness that it cannot be altered without causing a fracture, *i. e.*, when it has entirely lost its plasticity. Some cements set quickly, while others are comparatively slow. A quick-setting cement is especially valuable in constructions under water.

Test of Activity.—To test hydraulic activity mix cement with just enough clean water, at a temperature of from 65° to 70° F., to make a stiff paste and make one or two cakes or pats 2 or 3 inches in diameter and about $\frac{1}{2}$ inch thick. As soon as the cakes are prepared, immerse in water at 65° F. and note the time required for them to set hard enough to bear a $\frac{1}{12}$-inch wire loaded to weigh $\frac{1}{4}$ pound and 4 pounds, respectively. "When the cement bears the light weight it is said to have begun to set; when it bears the heavy weight it is said to have entirely set. Cements, however, will increase in hardness long after they can just bear the heavy wire. The *activity* of the cement is measured by the time which elapses between the time when the first weight is supported and that when the second is just borne." An increase of temperature will cause the cement to set quicker

while cold retards it. As a rule Portland cements should support the heavy wire in from two to five hours.

120. Soundness.—Tests for the soundness of Portland cement should be made in the same way as described in Section 113 for tests of Rosendale cement. The color of the cake dried in the air should be uniform bluish gray throughout, yellowish blotches indicating poor cement. The cake left in the water should be made with thin edges, and, if at the end of twenty-four hours it shows fine cracks around the edges, it is unsafe to use in damp places, but if there are no cracks it may be considered safe. This is a very simple test to make, and should be made in all cases where the cement is to be used under water.

121. Fineness.—There is no doubt that properly burnt cement, when ground extremely fine, is, as compared with one coarsely ground, much stronger when used with sand, as the finer the particles the better they can surround the sand and aggregates, thus more strongly cementing them together. The finely ground cement is also the safest to use. The hard-burnt cements, finely ground, make the strongest mortars.

Measuring Fineness.—"The degree of fineness of a cement is determined by measuring the per cent. which will not pass through sieves of a certain number of meshes per square inch." A cement that will pass through a sieve of 2,500 meshes (No. 35 wire gauge) with only 5 to 10 per cent. residue is sufficiently fine for any building construction.

122. Strength.—The most important test of cement is that of its strength. This is generally made by testing the tensile strength of the cement either neat or mixed with sand. Although cement mortar is generally subject only to a compressive strain, its resistance to compression is so much greater than to tension that in most cases of the failure of mortar it is broken by tensile stress.

Briquettes.—The method of testing the tensile strength of cement or mortar is to form a cake or brick of the cement or mortar in a mould, and after a certain limit of time it is pulled apart and the force required for producing fracture carefully noted. Figs. 57 and 58 show the shape of the briquette and the clamps for holding, as recommended by the Committee of the American Society of Civil Engineers.

The Machine.—There are many machines for sale, made especially for testing the strength of cement. Fig. 59, from Baker's "Treatise on Masonry Construction," represents a cement-testing machine that

can be made by an ordinary mechanic at small expense. It is not as convenient nor quite as accurate as the more elaborate machines, but it is sufficiently accurate for all practical purposes. "The machine

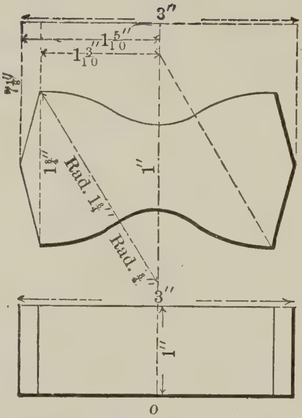

Fig. 57.

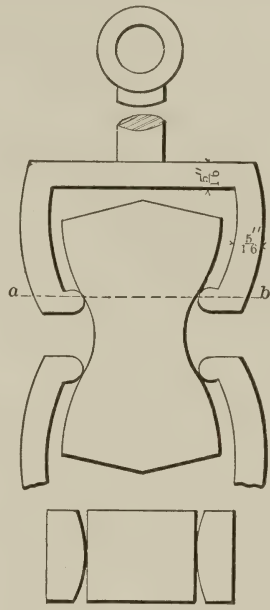

Fig. 58.

consists essentially of a counterpoised wooden lever, 10 feet long, working on a horizontal pin, between two broad uprights, 20 inches from one end. Along the top of the long arm runs a grooved wheel carrying a weight, W'. The distances from the fulcrum in feet and

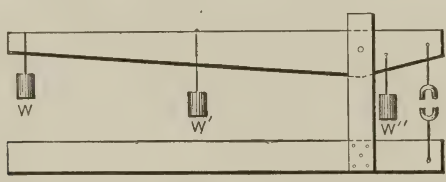

Fig. 59.

inches are marked on the surface of the lever, and also the corresponding effect of the weight at each point. The clamp, C, for holding the briquette is suspended from the short arm, 18 inches from the fulcrum. The clamps are of wood and are fastened by clevis joints to the lever arm and bed plate respectively. The pin is iron and the

pin holes are reinforced by iron washers. When great stresses are required extra weights are hung on the end of the long arm. Pressures of 3,000 pounds have been developed with this machine."

In applying the load on the briquette it is recommended that it start at 0 and be increased regularly at the rate of 400 pounds per minute for neat Portland cement, and 200 pounds per minute for natural cements and mortar.

A rough test may be made by suspending the clamps from a beam or trestle and hanging a bucket or box from the lower clamp, into which sand may be run until the briquette breaks, and the weight then weighed.

123. *Mixing the Mortar.*—Cements should be tested, both neat and mixed with sand. Briquettes made entirely of cement are more convenient for testing, as they may be tested sooner, and there can be less variation in the mixture. But in building, cement is rarely used without an admixture of sand, and the most valuable comparative test of different brands submitted would be to make the briquettes of cement and sand such as is to be used in the mortar, as while one cement might give a greater strength when used without sand, when mixed with the sand it might show a less result than another brand, owing to the comparative fineness of the two.

Practically the benefit to be obtained in testing the strength of cements for building purposes will be to determine which of the brands that are available are the most desirable, considering both the cost and the strength, although where a certain strength is specified the cement submitted by the contractor should be tested to see if it meets the requirements of the specifications.

In comparing different brands of cement great care should be used to see that the same kind and quality of sand is used in each case, as difference in the sand might cause as much difference in the results as there would be between the cements. It is recommended that an average of at least five briquettes of each brand of cement be taken as the strength of the cement.

The manner of making the briquettes should be as follows: On a thick glass plate lay sheets of blotting paper soaked in water, and on top of each sheet place a mould wetted with water. Before mixing the mortar an experimental batch should be made to determine the exact amount of water required to mix the cement to the proper consistency. If the cement is mixed with sand, both the cement and the dry sand should be carefully *weighed* to get the desired proportions, 1 to 1 or 1 to 3, as desired, and the sand and cement thoroughly

mixed dry in a tight box. All the water required for mixing should be added at once, and the whole mass thoroughly and rapidly mixed for five minutes. "With the mortar so obtained the moulds should be at once filled with one filling, so high as to be rounded on top, the mortar being well pressed in. The projecting mortar should then be pounded with a trowel, first gently and from the side, then harder into the moulds, until the mortar grows elastic and water flushes to the surface. A pounding of at least one minute is essential. The mass projecting over the mould should now be cut off with a knife and the surface smoothed." The briquettes should be removed from the moulds as soon as they are hard enough to stand it without breaking, and should be placed in a box lined with zinc and provided with a cover. The briquettes should remain in the box twenty-four hours, after which they should be placed under water, to remain until tested. They should be constantly covered with water until tested, which should be done as soon as they are taken from the water.

Age of Briquette for Testing.—Half of the briquettes are generally tested at the end of seven days, and the remainder at the end of twenty-eight days. If it is impracticable to wait twenty-eight days they may be tested at the end of one and seven days respectively, and the ultimate strength of the cement judged by the increase in strength between the two dates. When sand is used in making the briquettes it is desirable to wait until the briquettes are twenty-eight days old.

124. *Data on Strength.*—Table VIII., from the report of the Committee of the American Society of Civil Engineers on Uniform Tests of Cements, gives the results of the average minimum and maximum tensile strength per square inch which some good cements have attained when tested under the conditions above described.

TABLE VIII.—TENSILE STRENGTH OF CEMENT MORTARS.

AGE OF MORTAR WHEN TESTED.	AV. TENSILE STRENGTH IN POUNDS PER SQ. INCH.			
	PORTLAND.		ROSENDALE.	
Clear cement.	Min.	Max.	Min.	Max.
1 day—1 hour, or until set, in air, the remainder of the time in water.	100	140	40	80
1 week—1 day in air, remainder of the time in water	250	550	60	100
4 weeks—1 day in air, remainder of the time in water	350	700	100	150
1 year—1 day in air, remainder of the time in water	450	800	300	400
1 part cement to 1 part sand				
1 week—1 day in air, remainder of the time in water	....	...	30	50
4 weeks—1 day in air, remainder of the time in water	....	....	50	80
1 year—1 day in air, remainder of the time in water	....	....	200	300
1 part cement to 3 parts sand.				
1 week—1 day in air, remainder of the time in water	80	125	....	....
4 weeks—1 day in air, remainder of the time in water	100	200	....	....
1 year—1 day in air, remainder of the time in water	200	350	....	....

The quantities in the "Min." columns give the average strength of the weaker brands of Portland and Rosendale cements, and those in the "Max." columns the average strength for the stronger brands. By comparing his results with the values in this table, the architect or superintendent can judge whether his cement is satisfactory or not.

Limit to Increase of Strength with Age.—From a series of experiments made by Mr. Grant in England with a heavy cement, he was led to the conclusion that it attained its maximum strength after constant immersion for two years, and that there is no reason to fear that a good cement ever deteriorates. With a light cement the maximum strength would probably be attained much sooner.

125. Specifications for Cement.—In works where it is important to have a first-class cement the specifications should read about as follows, and all brands submitted should be carefully tested, and those which do not meet the requirements should be rejected:

Specification.—The whole of the cement shall be Portland cement of the very best quality, weighing not less than 110 pounds to the striked bushel, ground so fine that not over 10 per cent. will be rejected by a sieve of 2,500 meshes per square inch (No. 35 wire) and capable of maintaining a breaking weight of 350 pounds per square inch after hardening one day in air and six days in water, and shall show no cracks or blotches when left under water twenty-four hours.

Any cement that will fulfill these requirements should be good enough for any building construction or foundation.

126. *Lafarge Cement.*—This is a patented preparation of cement similar in character to Portland cement, made from a limestone of hydraulic properties. It is hydraulic in character, but, unlike Portland or Rosendale cement, does not stain marble, limestone and other porous stones when used in setting them, and therefore is especially desirable for setting such stones.

For setting large stones mix 1 part by volume of lime paste to 4 parts of the cement, to retard the setting of the cement until the stones are well bedded.

CEMENT MORTARS.

127. Use.—Cement mortar should be used for all mason work below grade, or where situated in damp places, also for heavily loaded piers and in arches of large span. It should be used for setting coping stones, and wherever the mason work is especially exposed to the weather.

For construction under water, and in heavy stone piers or arches, and for concrete, Portland cement should be used; elsewhere natural or Rosendale cement mortar will answer.

128. Mixing the Mortar.—For use in ordinary masonry cement mortar should be mixed about as follows: Spread about half the sand required for mixing evenly over the bed of the mortar box (which should be water tight), and then spread the dry cement evenly over the sand and spread the remaining sand on top. Thoroughly mix the dry sand and cement with a hoe or shovel, as this is a very essential part of the process. The dry mixture should be shoveled to one end of the box and water poured into the other end. "Cements vary greatly in their capacity for water, freshly-ground cements requiring more than those that have become stale. An excess of water is, however, better than a deficiency, particularly when a very energetic cement is used, as the capacity of this substance for absorbing water is great." The sand and cement should then be drawn down with a hoe in small quantities and mixed with the water until enough has been added to make a good *stiff* mortar, care being taken not to get it too thin. This should be vigorously worked with a hoe for five minutes to get a thorough mixture. The mortar should leave the hoe clean when drawn out of it, very little sticking to the steel. But a very small quantity of cement mortar should be mixed at a time, particularly that made of Rosendale cements, as the cement soon commences to set, after which it should not be used. As a rule natural cement mortars should not be used after they have been mixed two hours, and Portland cement mortars after four hours (for best work not over one hour).

The sand and cement should not be mixed so as to stand over night, as the moisture in the sand will destroy the setting qualities of the cement.

Should be Kept Moist.—"Hydraulic cements set better and attain a greater strength under water than in the open air; in the latter, owing to the evaporation of the water, the mortar is liable to dry instead of setting. This difference is very marked in hot, dry weather. If cement mortar is to be exposed to the air it should be shielded from the direct rays of the sun and kept moist."

129. Proportion of Sand.—"A paste of good hydraulic cement hardens simultaneously and uniformly throughout the mass, and its strength is impaired by any addition of sand." As mortar is never used by itself, however, but as a binding material for brick and stone, and there can obviously be no advantage in making the strength of

the mortar joints greater than that of the bricks or stones they unite, sand is always added to the cement in making mortar. As cement is much more expensive than sand, the larger the proportion of sand in the mortar the less will be its cost. The proportion of sand should vary according to the kind of cement and the kind of work for which the mortar is to be used. For natural cements the proportion of sand to cement by measurement should not exceed 3 to 1, and for piers and first-class work 2 to 1 should be used. Portland cement mortar may contain 4 parts of sand to 1 of cement for ordinary mortar, and 3 to 1 for first-class mortar. For work under water not more than 2 parts of sand to 1 of cement should be used. When cheaper mortars than these are desired it will be better to add lime to the mortar instead of more sand.

Plastering mortar, for stucco work or waterproofing, should be made of 1 part cement and 1 part sand. For lining cisterns 2 parts of natural cement or 1 of Portland cement should be used.

The following table shows the comparative strength of English Portland cement mortar, with different proportions of sand and at different ages:

AGE AND TIME IMMERSED.	PROPORTION OF CLEAN PIT SAND TO 1 CEMENT.					
	Neat cement.	1 to 1.	2 to 1.	3 to 1.	4 to 1.	5 to 1.
One week	445.0	152.0	64.5	44.5	22.0	.....
One month	679.9	326.5	166.5	91.5	71.5	49.0
Three months	877.9	549.6	451.9	305.3	153.0	123.5
Six months	978.7	639.2	497.9	304.0	275.6	218.8
Nine months	995.9	718.7	594.4	383.6	.....	.....
Twelve months	1,075.7	795.9	607.5	424.4	317.6	215.6

P. 177, "Notes on Building Construction," Part III.

The values in the table represent the breaking strength in pounds on a sectional area of $2\frac{1}{4}$ square inches. The superintendent should see that the cement and sand for each batch of mortar are carefully measured to get the right proportions.

130. Portland and Rosendale Cement, Mixed.—Whenever a quick-setting cement is desired, which shall attain a greater strength than the natural cements, a mixture of Portland and natural cement may be used. "Such mortar sets about as quickly as if made with natural cement alone, and acquires great subsequent strength, due to the Portland cement contained in it. The strength of the

mixed mortar is almost exactly a mean between that of the two mortars separate."

131. Lime with Cement.—An economical and strong mortar for use in dry places may be made by mixing Rosendale cement with lime mortar, in the proportion of 1 part of cement to 4 parts of lime mortar. The lime mortar should be *well worked and the lime thoroughly slaked before the cement is added*, and only a small quantity of the cement and lime mortar should be made up at a time. Such a mortar has a strength which is about a mean between that of lime mortar and Rosendale cement mortar, and which is amply sufficient for ordinary brickwork. Portland cement, mixed with lime mortar in the above proportion, gives no better results than good Rosendale cement. It is better to use a small proportion of lime with cement mortar than to use too large a proportion of sand, as the latter makes the mortar porous and liable to disintegrate rapidly. In England a mixture of Portland cement and lime mortar appears to be much used. Lime should not be added to cement mortar when it is to be used in wet places.

132. Grout is a very thin liquid mortar sometimes poured over courses of masonry or brickwork in order that it may penetrate into empty joints left in consequence of bad workmanship. It is also sometimes necessary to use it in deep and narrow joints between large stones. Its use is not generally recommended by writers on mortars, and the writer believes that it should not be used in stonework where it can be avoided. For brickwork, however, the author feels convinced that walls grouted with a moderately thin mortar every course makes a solid job. If the bricks are well wet before laying, and every joint slushed full of stiff mortar, it is impossible to get anything stronger ; but in most localities it is difficult to get such work without keeping an inspector constantly on the ground, and when the walls are grouted the joints are sure to be filled. In his own practice the author always specifies grouting for all brick footings and foundation walls. Many of the largest buildings in New York City have grouted walls.

133. *Data for Estimates.*—The following memoranda, made up from data given by Prof. Baker, will be found useful in estimating the amounts of materials required in making any given quantity of mortar:

Lime Mortar.—A barrel of lime weighs about 230 pounds ; a bushel of lime, 75 pounds. One barrel (or three bushels) of lime and

1 yard of sand will make 1 yard of 1 to 3 lime mortar, and will lay about 80 cubic feet of rough brickwork or common rubble.

Cement Mortar.—1.8 barrels, or 540 pounds, of natural cement and .94 cubic yards of sand will make 1 cubic yard of 1 to 3 mortar; two barrels, or 675 pounds, of Portland cement and .94 cubic yard of sand will also make 1 cubic yard of 1 to 3 mortar; 1.7 barrels, or 525 pounds, of Portland cement and .98 cubic yard of sand will make 1 cubic yard of 1 to 4 mortar; 1 cubic yard of mortar will lay from 67 to 80 cubic feet of rough rubble or brickwork, from 90 to 108 cubic feet of brickwork with $\frac{3}{8}$ to $\frac{1}{4}$-inch joints, and from 324 to 378 cubic feet of stone ashlar.

A cubic foot of common brickwork contains about eighteen bricks.

134. *Strength of Mortar.*—The exact strength of mortar to resist compression is not of very great importance, as it seldom, if ever, fails in this way. The tensile and adhesive strength of mortar is more important, particularly the latter, as whenever a building has fallen from using poor mortar it has generally been on account of the failure of the mortar to adhere to the bricks or stones. Whatever kind of mortar is used, it should be made rich and well worked, as the saving by using more sand is but a small percentage at most, and it is never safe for an architect to allow poor mortar to be used in his buildings.

The safe crushing strength of Portland, Rosendale and lime mortars used in $\frac{1}{2}$-inch joints should equal the following values in tons per square foot:

Portland cement mortar,	1 to 3,	3 months,	40 tons;	1 year, 65 tons.
Rosendale " "	1 to 3,	3 months,	13 tons;	1 year, 26 tons.
Lime mortar,	1 to 3,	3 months,	8.6 tons;	1 year, 15 tons.

From these values we see that for granite piers, heavily loaded, only Portland cement mortar should be used. For all piers loaded with over 10 tons per square foot, and not exceeding 20 tons, Rosendale cement mortar should be used. Lime mortar should never be used for piers that are to receive their full load within six months.

135. "*The adhesion of mortars* to brick or stone varies greatly with the different varieties of these materials, and particularly with their porosity. The adhesion varies also with the quality of the cement, the character, grain and quantity of the sand, the amount of water used in tempering, the amount of moisture in the stone or brick, and the age of the mortar."

Mortar adheres to both stone and brick better when they are wet (unless the temperature is below the freezing point), and the architect

should always insist on having the bricks well wet down with a hose before laying. A dry brick absorbs the moisture from the mortar so that it cannot harden properly and destroys its adhesive properties. *The wetting of the brick* is fully of as much importance as the quality of the mortar in brickwork. The adhesive strength of the cements and lime are as a rule in proportion to their tensile strength. Therefore where great adhesive strength is desired to prevent sliding, as in arches, etc., either Portland or Rosendale cement should be used, according to the importance of the work and stress to be resisted. Some years ago the walls of a brick building in New York City were pushed outward by barrels of flour piled against the walls, so that the walls suddenly fell into the street. An examination of the mortar showed that it was of poor quality, with little adhesion to the bricks. Had good mortar been used and the brick well wet, the failure (it should not be called an accident) would not have occurred. The adhesive and tensile strength of mortar is also of great importance in resisting wind pressure and vibration.

136. *Mortar Impervious to Water.*—A frequent case of the failure of masonry is the disintegration of the mortar in the outside of the joints, although this does not take place to such an extent in buildings as in engineering works. "Ordinary mortar—either lime or cement—absorbs water freely, common lime mortar absorbing from 50 to 60 per cent. of its own weight, and the best Portland cement mortar from 10 to 20 per cent., and consequently they disintegrate under the action of the frost. Mortar may be made practically non-absorbent by the addition of alum and potash soap. One per cent., by weight, of powdered alum is added to the dry cement and sand and thoroughly mixed, and about 1 per cent. of any potash soap (ordinary soft soap made from wood ashes is very good) is dissolved in the water used in making the mortar. The alum and soap combine and form compounds which are insoluble in water. These compounds are not acted upon by the carbonic acid of the air, and add considerable to the early strength of the mortar and somewhat to its ultimate strength." * The alum and soap are comparatively cheap and can be easily used.

The mixture could be advantageously used in plastering basement walls and on the outside of buildings, and would add greatly to the durability of mortar used for pointing.

137. *Plaster of Paris in Mortar.*—Plaster of Paris, which is sulphate of lime, when added to either lime or cement mortar in

* "Treatise on Masonry Construction," Baker.

quantities not exceeding 5 per cent., accelerates the setting and also increases the early and the ultimate strength of mortar. Lime mortar to which plaster of Paris has been added is called gauged mortar. *Selenetic cement*, an artificial cement much used in England, is made by combining plaster of Paris and hydraulic lime, in the proportion of three pints of the plaster to a bushel of unslaked lime. The addition of the plaster of Paris to lime appears to increase the strength of the mortar from two to three times.

138. *Sugar in Mortar.*—Sugar has been employed for centuries in India as an ingredient of common lime mortar, and adds greatly to the strength of the mortar.

An addition of sugar or syrup equal to one-tenth of the weight of the unslaked lime, to lime mortar, adds 50 per cent. to the strength of the mortar and will cause the mortar to set more quickly. The addition of sugar to lime mortar is especially beneficial when used in very thick walls, as the lime mortar thus placed never becomes fully saturated with carbonic acid.

Sugar added to Rosendale and Portland cement mortars in the proportion of $\frac{1}{8}$ to $\frac{1}{4}$ per cent. in weight of the cement, increases the strength of the mortars about 25 per cent.

As the combination of sugar and lime is soluble in water, sugar should not be added to mortar that is to be used under water.

139. *Freezing of Mortar.*—Freezing does not appear to injure lime mortar *if the mortar remains frozen until it has fully set.* Alternate freezing and thawing materially damages the strength and adhesion of lime mortar, and as this is generally what happens when mortar is laid in freezing weather, it is much the safest rule for the architect to specify and see that no masonry shall be laid with lime mortar in freezing weather. "Mortar composed of 1 part *Portland cement* and 3 parts of sand is entirely uninjured by freezing and thawing. mortar made of *cements* of the *Rosendale type*, in any proportion, is entirely ruined by freezing and thawing." *

Salt in Mortar.—When it is desired to use natural cement mortar in freezing weather the mortar should be mixed with water to which salt has been added in the proportion of one pound of salt to eighteen gallons of water, when the temperature is at 32° F., and for each degree of temperature below 32° add three additional ounces of salt. Mortar mixed with such a solution does not freeze in ordinary winter weather, and hence is not injured by frost.

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* Trans. Am. Soc. of C. E., Vol. XVI., pp. 79-84.

When masonry must be laid in freezing weather the bricks or stones should be warmed sufficiently to thaw off any ice upon their surface or in the pores of the bricks before being laid.

Builders sometimes advocate the addition of lime to Rosendale cement mortar in cold weather to *warm it.* The heating effect of the lime, however, would not be appreciable, as heat is generated in lime only when it slakes. If cement of the Rosendale type must be used in freezing weather, the only safe way of using it is by the addition of salt, as described above, otherwise the mortar will be completely ruined by freezing.

Change of Volume in Setting.—Cement mortars diminish slightly in volume in setting in air and expand when under water, but the expansion and contraction is not sufficient to injuriously affect building construction.

CONCRETE.

140. There is probably no material that is so enduring, or better adapted for foundations (and also walls, vaults, etc.), than cement concrete, and perhaps none that is so much "skimped."

Concrete may be defined as an artificial rock, made by uniting sand, broken stone, gravel, fragments of brick, pottery, etc., by means of lime or cement.

Concrete made with lime, however, is not suitable for damp situations, and even when used for walls above ground it is much better to use either a "Portland" or "natural" cement for the uniting material.

Concrete made with good Portland cement, in proper proportions, becomes so hard and strong that when pieces of the concrete are broken the line of fracture will often be found to pass through the particles of stone, showing that the adhesion of the cement to the stone is greater than the strength of the stone.

For the aggregates no material is better than clean, freshly broken stone, in size about as large as a hen's egg. Granite probably makes the best aggregates, but other hard stones will answer for any ordinary concrete. Soft sandstones or "freestones" are not desirable. Pieces of hard brick or dense terra cotta also make good aggregates.

Whatever material is used it is essential that it be free from dirt and that the particles be clean.

Good clean, coarse gravel is also extensively used for the mass of the concrete, and some architects and builders prefer it to broken stone, but as all gravel has more or less rounded and smooth surfaces,

it would seem as though the cement must adhere more firmly to angular and broken surfaces.

A certain proportion of clean, coarse sand is also required to fill the voids between the particles of stone or gravel.

The method of making and using concrete is very simple, but owing to the fact that it is impossible to tell from an examination of the product the amount of cement that has been used, and the great temptation to the contractor to use as little cement as possible, not more than one-half or two-thirds of the amount of cement specified is generally used (unless an inspector is kept on the work), and the mixing of the materials is also often very imperfectly done.

141. Measuring the Materials.—The only proper way to make concrete is by carefully measuring the proportions of cement, sand, broken stone, etc. This may readily be done by using the common mason's wheelbarrow for a unit of measure and mixing together the specified number of barrows of each material.

For ordinary building operations, where the concrete is mixed by hand, as much concrete as may be made by two barrows of cement is all that can be worked at one time to advantage. The ordinary barrel of cement will just about fill two barrows, so that one barrel of cement may be considered as equal to two barrows, or parts. If the proportion is specified in this way, however, the inspector should have a barrel emptied into two barrows, and then permit the barrows to be filled with the sand and gravel only to the extent that they are filled by the cement.

142. Manner of Mixing.—The most satisfactory method of mixing concrete by hand is to first prepare a tight floor of plank, or, better still, of sheet iron with the edges turned up about 2 inches, for mixing the materials on.

Upon this platform should first be spread the sand, and upon this the cement. The two should then be thoroughly and immediately mixed by means of shovels or hoes, and the broken stone or aggregates then dumped on top and the whole worked over dry with shovels, and then worked over again while water is added from a sprinkler on the end of a hose. Only as much water should be added as is necessary to cause the cement to completely coat and cause to adhere all the particles of the aggregates. Too much water will lessen the strength of the concrete.

The water used should be clean and at about the temperature of 65°.

There are many machines for mixing mortar, which, for large quantities of concrete, effect a saving in the cost of mixing, and

probably do the work more thoroughly and evenly. As soon as the concrete is mixed it should be wheeled to the trenches in barrows and dumped.

Instead of first mixing the cement and sand, very good results may be obtained, with perhaps a little less labor, by depositing the broken stone on the sand after it is spread over the platform, and then the cement on top of the stone, and working the whole over dry with shovels. The first method, however, is to be preferred where an extra quality of concrete is desired.

143. **Proportions.**—The best proportion of cement, sand and aggregates will depend upon the kind and quality of the cement used and the character of the work.

The proportion of sand to aggregates should be such that the sand will just fill the voids in the aggregates. This will, of course, vary with the size of the aggregates and the coarseness of the sand. For stone broken to go through a 2½-inch ring, about one-half as much sand as stone is required, on an average, to fill the voids. After one batch of concrete has been deposited and rammed the inspector can generally tell by the appearance whether too much or too little sand has been used.

Natural Cement Concrete.—For concrete foundations under buildings of moderate height, and for foundations for cement pavements, natural cements make as strong concrete as is required.

For the best brands of natural cements 1 part cement, 2 parts sand and 4 parts gravel or broken stone should be used.

[This proportion was used in the foundations of the Brooklyn Bridge.]

Portland Cement Concrete.—For concrete to be used under heavy buildings and under water Portland cement should be used.

For the best brands of cement 2 parts of cement to 5 of sand and 9 of broken stone will answer for almost any building construction. Much larger proportions of sand and aggregates than these are often used, but the author would not recommend a greater proportion than the above unless the quality of the cement is constantly tested and only the best used, and the concrete mixed under rigid inspection.

144. *Examples of Portland Cement Concrete.*—Foundations of Mutual Life Insurance Company's Building, New York: 1 part cement, 3 parts sand, 5 parts broken stone.

Foundation of U. S. Naval Observatory: 1 part cement, 2½ sand, 3 gravel, 5 broken stone. [1 barrel of cement, 380 pounds, made 1.18 yards of concrete.]

Foundations of Cathedral of St. John the Divine, New York: 13,000 cubic yards of concrete have been used in the foundation of the tower and choir, the average depth being 15 feet. Proportions: 1 part Portland cement, 2 parts sand, 3 parts quartz gravel, 1½ to 2 inches in diameter.

Filling of caissons, Johnston Building (fifteen stories) New York: 1 part Portland cement, 3 parts sand, 7 parts stone, finished on top for brickwork with 1 part cement and 3 parts gravel.

Manhattan Life Insurance Building, New York, filling of caissons: 1 part Alsen Portland cement, 2 parts sand, 4 parts broken stone.

The proportion of cement is sometimes specified as "one barrel of cement to a yard of concrete," but as it is very inconvenient to measure the concrete by the yard such a specification is not to be recommended.

145. Depositing.—As soon as a batch of concrete is mixed it should be wheeled to the trenches and deposited in layers from 6 to 10 inches in thickness. Where the total thickness of concrete does not exceed 18 inches the layers should not be more than 6 inches thick. The concrete should not be dumped from a greater height than 4 feet above the bottom of the trench. If dumped from a greater height the heavy particles are apt to separate from the lighter ones.

As soon as a square yard of concrete has been deposited it should be tamped with a wooden rammer weighing about 20 pounds. The tamping should be sufficient to just flush the water to the surface. The concrete should not be permitted to dry too quickly, and if twenty-four hours elapse between depositing the successive layers the top of each layer should be sprinkled before the next is deposited.

146. Strength of Concrete.—The writer is not acquainted with any reliable tests on the compressive strength of concrete, but it is generally assumed that the strength of thoroughly mixed concrete is equal to that of mortar made of the same proportions of sand and cement. The crushing strength of 6-inch cubes of 1 to 2 Portland cement mortar was found by tests made at the Watertown Arsenal to average about 500 pounds per square inch, or 36 tons per square foot. For the working strength of concrete the author recommends the following values, the larger values being for work done under strict inspection with the best of cement:

Portland cement concrete, 1 to 8, 8 to 20 tons per square foot; natural cement concrete, 1 to 6, 5 to 10 tons per square foot.

The estimated weight to be imposed on the concrete footings of the Cathedral of St. John the Divine is 10 tons per square foot.

147. Data for Estimating.—There seem to be few records of careful measurements of the amount of materials required to make a cubic yard of concrete, but the following data is believed to be reasonably accurate:

Used in the proportion of 1 part cement, 3 of sand and 5 of broken stone, in sizes not exceeding 2x1½x3 inches, one barrel of cement will make from 22 to 26 cubic feet of concrete, the average being about 23 cubic feet.

In putting in the foundations of the Cathedral of St. John the Divine, New York, it required 17,000 barrels of Portland cement to make 11,000 yards, or about one and one-half barrels to the yard. The proportions were 1, 2 and 3.

Concrete made of 1 part cement, 2½ of sand, 3 of gravel and 5 of broken stone gave 1.18 yards of concrete to a barrel of cement.

The ordinary cement barrel contains about 3¾ cubic feet.

At $2 a day for labor, the cost of mixing and depositing concrete should not exceed $1 a cubic yard. The cost per yard of Portland cement concrete will generally vary from $6 to $8, according to the cost of the cement, labor and aggregates.

MORTAR COLORS AND STAINS.

148. The use of artificial coloring in mortars has been in vogue, more or less, for two thousand years, but the general use of colored mortars dates from a comparatively recent period.

The object aimed at in using colored mortars is either to get the effect of a mass of color, by concealing the joints, or else, by using a contrasting color, to emphasize the joints. Rougher bricks may also be used with nearly as good effect by using a mortar of the same color as the bricks. Chipped or uneven edges do not show as plainly with mortar of the same color as the bricks as they do when laid with white mortar.

Objections to Mortar Colors.—The objection is sometimes made to the use of colored mortars that they are not as strong as white mortars and that the color is very apt to fade.

These objections undoubtedly have much truth in them when cheap colors are used and the mortar is not properly mixed, but it is very doubtful if the better grades of mortar colors now on the market affect the strength of the mortar to any appreciable extent, and when properly mixed with lime putty they seldom, if ever, fade.

149. Kinds of Colors.—Most, if not all, of the coloring materials sold under the name of "mortar colors," or stains, consist of mineral

pigments put up either in the form of a dry powder or in the form of a pulp or paste.

Pulp colors are said to be susceptible of more uniform mixing with the mortar than dry colors, and, as a rule, appear to have the preference for the better grades of work.

Paste or pulp stains should not be allowed to freeze, and should be kept moist by covering with water.

A great deal of colored mortar is made by using Venetian red, or the cheap grades of mineral paints for the coloring matter. The ordinary Venetian red is very apt to fade and also weakens the mortar, and the cheaper grades of mineral colors are not much better. The cost of the coloring matter is so small an item that only the very best grades should be used.

Among the brands of mortar colors generally recognized as belonging to the first grade are the "Clinton," "Peerless," "Pecora" "Edinburgh," "American Seal," "Milwaukee" and "Cabot."

The principal colors used are red, brown, buff and black, although green, purple, gray and drab mortar colors are also made.

150. Mixing.—Mortar colors, whether in dry or paste form, should not be mixed with lime until the latter has been slaked at least twenty-four hours, and the best way is to keep a lot of lime putty on hand and mix the color with it as needed.

The color should be thoroughly and evenly mixed with the putty before the sand is added, and for very fine work the colored putty should be strained through a coarse sieve.

For cement work the stain should be thoroughly mixed with the sand or gravel and set aside in barrels, and the cement added in small quantities as required for use.

Like all water paints, the color of the mortar looks different in the bed than when dry. To get the final color of the mortar a little should be taken from the bed and permitted to dry thoroughly, when the permanent color may be seen.

The amount of coloring matter required to stain a given quantity of mortar varies with the different colors and brands. The following quantities may be taken as the average amounts required in laying one thousand face brick :

Red or terra cotta, 50 pounds.

Buff, brown or French gray, 25 pounds.

Black, 22 pounds.

Chapter V.

BUILDING STONES.

It is important that an architect should have some knowledge of the nature of the different kinds of stone, that he may know what stone is best to use under any given circumstances, and what stones not to use. It can hardly be expected that an architect shall be a geologist, a mineralogist or a chemist, and thus capable of determining the exact composition of a stone, but it is expected of him that he shall know enough of the subject to specify stones that shall have sufficient strength and durability and that will not become discolored through chemical changes in their constituents.

To acquire such a knowledge of building stones requires not only a study of their mineral constituents and of their structure, but also accurate observation and much experience with stones.

The following short description of the principal building stones of this country, with the localities in which they are quarried, will enable the young architect to get some idea of their composition and characteristics, and, it is hoped, assist him in making a judicious selection of stones for special cases.* The stones are classed according to their structure and composition.

151. Granite, Gneiss and Syenite.—The granites are massive rocks occurring most frequently as the central portions of mountain chains. They are a hard, granular stone, composed principally of quartz, feldspar and mica, in varying proportions. When the stone contains a large proportion of quartz it is very hard and difficult to work. When there is a considerable proportion of feldspar the stone works more easily.

The color of the granite is principally determined by the color of the feldspar, but the stone may also be light or dark, according as it contains light or dark mica. The usual color of granite is either a light or dark gray, although all shades from light pink to red are found in different localities.

* For a complete work on the subject the reader is referred to "Stones for Building and Decoration," by George P. Merril, Ph.D.; John Wiley & Sons, publishers. Much valuable information relating to building stones may also be found in the various numbers of *Stone*.

The light fine-grained stones are the strongest and most durable, although almost every granite has sufficient strength for ordinary building construction. It generally breaks with regularity and may be readily quarried, but it is extremely hard and tough and works with great difficulty, so that it is a very expensive stone to use for cut work. It is impossible to do fine carving in most granites. Granite is one of the best stones for foundations, base courses, water tables, etc., and for columns and all places where great strength is required; also for steps, thresholds and for flagging, when it can be slit readily.

Excellent varieties of granite may be obtained in any of the New England States and in most of the Southern States and the Rocky Mountain region, and in California and Minnesota.

As a rule granite can be quarried in any size desired. New quarries should be analyzed to see if they contain iron, in which case it would be dangerous to use the stone for ornamental purposes until its weathering qualities have been thoroughly tested by exposing blocks for a long time to the weather. If the iron is a sulphurate it is quite sure to stain the stone.

Gneiss (pronounced like nice) has the same composition as granite, but the ingredients are arranged in more or less parallel layers. On this account the rock split in such a way as to give parallel flat surfaces, which renders the stone valuable for foundation walls, street paving and flagging. Gneiss is generally taken for granite, and is frequently called by quarrymen *stratified* or *bastard* granite.

Syenite is a rock also resembling granite, but containing no quartz. It is a hard, durable stone, generally of fine grain and light gray color. The principal syenite quarries in this country are near Little Rock, Arkansas.*

All three of these stones are badly affected by fire, large pieces breaking off and the stone cracking badly.

Fox Island, Me.; Groton, Conn.; Woodstock, Md.; St. Cloud, Minn., and Nova Scotia granites are spoiled at 900° F. Hallowell, Me.; Red Beach, Me.; Oak Hill, Me., and Quincy, Mass., granites are spoiled at 1,000° F. The granites standing the highest fire tests are: Barre, Vt.; Concord, N. H.; Ryegate, Vt.; Mt. Desert, Me.

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* In many books and papers treating on granite, syenite is described as a rock consisting of quartz, feldspar and hornblende, the latter taking the place of the mica in the true granites. According to the modern methods of classification such rocks are called "hornblende granite."

"The name 'syenite' takes its origin from Syene, Egypt, but the stone from which it was named has been found to contain more mica than hornblende. According to recent lithologists the Syene rock is a hornblende, mica granite, while true syenite, as above stated, is a quartzless rock."—*Merrill.*

152. Description of some of the best known Granites.

Vinalhaven, Fox Island, Me.—These quarries are the most extensive in the country; texture of stone rather coarse; color, gray; contains a small amount of hornblende. It takes a good and lasting polish, and is well adapted for all manner of ornamental work and general building purposes. The stone has been used extensively all over the country for both building and monumental purposes.

Hallowell, Me.—This stone is celebrated for its beauty and fine working qualities, and is in great demand for monuments and statuary. It is a fine light gray rock, comparatively pure, the principal constituents being quartz, feldspar and mica. Has been used extensively all over the country.

There are many other quarries of fine granite in Maine.

Quincy, Mass.—The Quincy granite quarries are amongst the oldest in the country. The product is, as a rule, dark blue-gray in color, coarse grained and hard. Composition: quartz, hornblende and feldspar. The polished stairways and pilasters in the new City Hall at Philadelphia are of this stone.

Concord, N. H.—A fine-grained granite, light gray color, with a silver lustre; well-developed rift and grain, and remarkable for the ease with which it can be worked. Constituents: opaque quartz, soda feldspar and white mica. Well adapted for statuary and monumental purposes, as well as for general building. The stone is eminently durable, the New Hampshire State House, built of this stone in 1816-19, being still in an excellent state of preservation. The Congressional Library building, Washington, D. C., is built of this stone.

North Conway, N. H.—A coarse-grained granite; colors, red and green, the red being the principal variety. Contains both hornblende and pyroxene. Used in the Union Depot, Portland, Me.

Westerly, R. I.—Granite of fine grain and even texture and of excellent quality. Constituents: quartz, feldspar and mica, with some hornblende. Color, rich light gray or pink, with a distinct tint of brown when polished.

Jonesborough, Me.—At this place is quarried a pink or reddish granite, which is generally considered as the best American red granite at present quarried. The stone is very compact and hard, and much finer in texture than the celebrated red Scotch granite.

St. Cloud, Minn.—Both gray and red granites are quarried at this place; the latter greatly resembles the Scotch granite in color, grain and polish. The gray granite is about one-third quartz and two-thirds feldspar.

Graniteville, Mo.—Here is quarried a very hard red granite, mottled with gray and black, which takes a handsome polish. The stone has been used in many important buildings in St. Louis, Kansas City and Chicago.

Colorado.—This State also contains great quantities of granite, which, however, have been but little developed. The principal quarry is at Gunnison, which produces a blue-gray granite, which may be seen in the Colorado State House.

Georgia.—Excellent grades of light and dark gray granite are contained in this State, but as yet they are developed only to a small extent.

153. Limestone.—This name is commonly used to include all stones which contain lime, though differing from each other in color, texture, structure and origin. All limestones used for building purposes contain one or more of the following substances, in addition to

lime: Carbonate of magnesia, iron, silica, clay, bituminous matter, mica, talc and hornblende.

There are three varieties of limestone used for building purposes, viz.: *Oolitic limestone*, *magnesian limestone* and *dolomite*.

Oolitic limestones are made up of small rounded grains (resembling the eggs of a fish) that have been cemented together with lime to form a solid rock.

Magnesian limestones include those limestones which contain 10 per cent. and over of carbonate of magnesia.

Dolomite is a crystalline granular aggregation of the mineral dolomite, and is usually whitish or yellowish in color. It is generally heavier and harder than limestone.

All varieties of limestone are liable to contain shells, corals and fossils of marine animals, more or less pulverized. A limestone can be identified by its effervescence when treated with a dilute acid.

Many of our finest building stones are limestones, but as they are less easily and accurately worked than sandstones they are not so largely used except in the localities where the best varieties are found.

The color of limestone is generally a light gray, though it is sometimes a deep blue, and occasionally of a cream or buff color. The light gray varieties often resemble the light, fine-grained granites in appearance.

Most of the granular limestones are susceptible of a high polish.

Good limestone should be of a fine grain and weigh about 145 pounds per cubic foot.

The limestones described below are very durable, but the light-colored stones are apt to become badly stained in large cities, and especially in those cities in which soft coal is used.

All kinds of limestone are destroyed by fire, although some varieties will stand a greater degree of heat without injury than others.

154. Description of Limestones.—The limestones most extensively used for building purposes come from the States of Illinois, Indiana, Ohio, New York and Kentucky.

The most celebrated American limestone is that quarried at *Bedford, Indiana*, which is a light-colored oolite, consisting of shells and fragments of shells (so minute as to be scarcely discernible by the naked eye), cemented together by carbonate of lime.

This stone is most remarkably uniform in grain and texture, is exceedingly bright and handsome in color, and is less liable to discolor than most light stones.

It is equally strong in vertical, diagonal and horizontal directions, and when first quarried is so soft as to be readily worked with a saw or chisel; it hardens, however,

on exposure, and attains a strength of 10,000 to 12,000 pounds per square inch. Owing to its fine and even grain and ease in cutting in any direction, it is especially adapted for fine carving. The stone is also very durable.

On account of its many excellent qualities it was selected by the architect for Mr. George W. Vanderbilt's palatial residence at Biltmore, N. C. The Auditorium Building at Chicago, the Manhattan Life Building, New York ; the mansion of Mr. C. J. Vanderbilt on Fifth Avenue, New York ; the State House at Indianapolis and many other prominent buildings are built of this stone. There are several quarries of this stone, the products varying somewhat in color and quality.

A gray limestone is quarried at *Lockport, N. Y.*, which is extensively used for trimmings in that State and some parts of New England.

There are large quarries of limestone at Dayton and Sandusky, Ohio ; Joliet, Grafton and Chester, Illinois, and in the vicinity of Topeka, Kansas. There are several small quarries which supply the local demand in various parts of Kansas. The Topeka stone can be worked almost as easily as wood, and yet becomes hard and durable when placed in the building.

At *Carthage, Jasper County, Missouri,* there are extensive quarries of limestone, which produce large quantities both of quicklime and building stone. The stone is coarse grained and crystalline, takes a good polish, and is well adapted to exterior finishing.

Excellent quarries of limestone also exist at Phœnix, Missouri, the stone being shipped to St. Louis, Kansas City and Omaha.

Kentucky.—This State also contains a great quantity of fine limestone, some varieties of which are said to be equal, if not superior, to the Bedford stone. The best known of the Kentucky limestones is probably the Bowling Green (oolitic) stone, quarried at Memphis Junction. This stone is almost identical in composition with the celebrated "Portland" stone of Great Britain. Its color is light gray. It is as readily worked as the Bedford stone, is very durable, and is pre-eminent in its resistance to the discoloring influences of mortar, cement and soil.

MARBLE.

155. Marble is simply a crystallized limestone, capable of taking a good polish.

The scarcity and consequent expense of good marbles have in the past prevented them from being used in constructional work, except occasionally for columns. Most of the marbles obtained from the older quarries also stain so easily that they are considered undesirable for exterior work.

Since the rapid development of the Georgia and Tennessee marble quarries, however, stone from these quarries has been much used for exterior finish, and even for the entire facing of the walls. These marbles will probably be more extensively used for exterior work in the future, as they are exceedingly strong and durable and do not stain readily.

Nearly all varieties of marble work comparatively easy, and the fine-grained varieties are especially adapted for fine carving.

They generally resist frost and moisture well, and are admirably suited for interior decoration, sanitary purposes, etc., and in clear, dry climates make a splendid material for exterior construction.

The strength of marble varies from 5,000 to 20,000 pounds per square inch, and only when used for columns need its strength be considered.

[For the composition and strength of various marbles see tables in appendix.]

156. Description of Leading American Marbles.—Great quantities of white and black marble are quarried in this country, but nearly all of the beautiful streaked and colored marbles are imported.

The States which produced marble in 1894 were California, Georgia, Idaho, Maryland, New York, Oregon, Pennsylvania, Tennessee and Vermont.

Vermont Marble.—This State is the greatest producer of marble of any State in the Union, the total product in 1889 amounting to $2,169,560, more than the combined value of all other marbles quarried in the country.

The largest quarries are at West Rutland and Sutherland Falls (Proctor).

In texture Vermont marble is, as a rule, fine grained, although some of it is coarse grained and friable. In color it varies from pure snowy white through all shades of bluish, and sometimes greenish, often beautifully mottled and veined, to deep blue-black; the bluish and dark varieties being, as a rule, the finest and most durable.

These marbles are used principally for monumental and statuary work, and for decorative work, sanitary fittings, tiling, etc., in buildings.

At Sutherland Falls the stone is very massive, and large blocks are taken out for general building purposes.

Tennessee.—Marble has been quarried in this State since 1838, the principal quarries being in the vicinity of Knoxville, in East Tennessee. The varieties of marble produced from these quarries embrace grays, light pinks, dark pinks, buffs, chocolate and drabs. Only the pinks and grays, however, are suitable for general building purposes, the darker colors being principally confined to furniture and interior work. The stone is 98 per cent. carbonate of lime. The pink and gray varieties are well adapted for building purposes, their density and resistance to crushing being equal to that of any other marble produced in the world.

They also offer great resistance to moisture, and are practically impervious to the staining or discoloring agencies of the atmosphere, except, perhaps, in large manufacturing centres. Under favorable conditions there appears to be no reason why these marbles should not last for ages on the exterior of buildings. The highly colored varieties are amongst the handsomest produced in this country.

Georgia.—This State contains extensive beds of marble, which, however, have only recently been quarried on a commercial scale. The quarries, which are situated in the northern part of the State, produce: 1st. A clear white marble, bright and sparkling with crystals. 2d. A dark mottled white ground, with dark blue mot-

tlings; also a light blue and gray ground, with dark mottlings. 3d. White, with dark blue spots and clouds, and a bluish-gray, with dark spots and clouds. 4th. Pink, rose tints and green in several shades. The appearance of the Georgia marbles is quite different from that of the marbles from the other States.

The stone is a pure carbonate of lime, entirely free from foreign or hurtful ingredients. It is remarkably non-absorbing, and absolutely impervious to liquids (even ink), atmospheric changes and decay, and not subject to discoloration. If soiled by dust or smoke it can be easily cleaned by washing with clean water only so as to look as bright as when first finished.

Georgia marble has been extensively used for monuments and for the interior finish of buildings, notably in the new Congressional Library. It is also used more and more every year for exterior construction, either as trimmings or for the entire wall. It may be seen in the exterior of the Ames Building at Boston, the Equitable Building at Baltimore, St. Luke's Hospital at New York and many other prominent buildings.

New York.—There are several quarries of gray, blue and white marble near New York City which furnish good building marble, but not quite good enough for decorative work. Much of it has been used for building purposes in New York City.

The best quality of black marble is quarried at Glens Falls, on the Hudson River. In *Montgomery County*, *Pennsylvania*, are several quarries of a granular white and mottled marble, which have furnished a great deal of marble for Philadelphia buildings.

Colorado and California also contain beautiful varieties of marble, which it is thought may in time take the place of much of the foreign marble now imported. At present only a very few quarries are worked, and these only to a slight extent.

157. **Onyx Marble.**—These stones are of the same composition as common marbles, but were formed by chemical deposits instead of in sedimentary beds, crystallized by the action of heat. "They owe their banded structure and variegated colors to the intermittent character of the deposition and the presence or absence of various impurities, mainly metallic oxides. The term onyx as commonly applied is a misnomer, and has been given merely because in their banded appearance they somewhat resemble the true onyx, which is a variety of agate."

Owing to their translucency, delicacy and variety of colors, and the readiness with which they can be worked and polished, the onyx marbles are considered the handsomest of all building stones, and they also bring the highest price, the cost per square foot for slabs 1 inch thick varying from $2.50 to $6. Their use is confined to interior decoration, such as wainscoting, mantels, lavatories, and for small columns, table tops, etc. Most of the onyx marble used in the United States is imported from Mexico, although considerable onyx is quarried at San Luis Obispo, California, and quarries of very beautiful stone have recently been opened near Prescott, Arizona. The Mexican onyx presents a great variety of colors, creamy white, amber

yellow and light green, generally more or less streaked or blotched with green or red. Some of the light stones have a beautiful translucent clouded effect. When cut across the grain the stone often presents a beautifully banded structure like the grain of wood. Cutting the stone across the grain, however, greatly weakens its strength, so that it is necessary to back it with slabs of some stronger marble.

The San Luis Obispo stone is nearly white, finely banded, translucent, and takes a beautiful surface and polish.

The Arizona stone presents a greater variety of coloring, from milky white to red, green, old gold and brown, intermingled in every possible way. But a comparatively small amount of this stone is as yet on the market, but further developments will probably result in the production of a great quantity of the stone.

158. Sandstones.—"Sandstones are composed of rounded and angular grains of sand so cemented and compacted together as to form a solid rock. The cementing material may be either silica, carbonate of lime, an iron oxide or clayey matter."

They include some of the most beautiful and durable stones for exterior construction, and on account of the ease with which they can be worked and their wide distribution throughout the country, are more extensively used for exteriors than any other stone.

The grains of sand themselves are nearly the same in all sandstones, being generally pure quartz, the character of the stone depending principally upon the cementing material. If the cementing material is composed entirely of silica, the rock is light colored and generally very hard and difficult to work. When the grains have been cemented together by fusion or by the deposition of silica between the granules, and the whole hardened under pressure, it is almost the same as pure quartz and is called *quartzite*—one of the strongest and most durable of rocks. "If the cementing material is composed largely of iron oxides the stone is red or brownish in color and usually not too hard to work readily. When the cementing material is carbonate of lime the stone is light colored or gray, soft and easy to work." Such stones do not as a rule weather well, as the cementing material becomes dissolved by the rain, thereby loosening the grains and allowing the stone to disintegrate. Clay is still more objectionable than lime as a cementing material, as it readily absorbs water and renders the stone liable to injury by frost.

In some sandstones part of the grains consist of feldspar and mica, which have a tendency to weaken the stone.

Sandstones are of a great variety of colors; brown, red, pink, gray, buff, drab or blue, in varying shades, being common varieties; the color being due largely to the iron contained in the stone. The *oxides* of iron do no harm in the stone, but no light-colored sandstone should be used for exterior work which contains *iron pyrites* (or sulphate of iron), as the iron is almost sure to stain or rust the stone.

Sandstones vary in texture from almost impalpable fine-grained stones to those in which the grains are like coarse sand. All other conditions being the same, the fine-grained stones will be the strongest and most durable and take the sharpest edge. Sandstones being of a sedimentary formation, they are often laminated, or in layers, and if the stone is set "on edge," or with its natural bed or surface parallel to the face of the wall, the surface of the stone is quite sure in time to disintegrate or peel off. All laminated stones should always be laid on their natural bed. When freshly quarried, sandstones generally contain a considerable quantity of water, which makes them soft and easy to work, but at the same time very liable to injury by freezing if quarried in winter weather. Many Northern quarries cannot be worked in winter on this account. Most, if not all, sandstones harden as the quarry water evaporates, so that many stones which are very soft when first quarried become hard and durable when placed in the building. Such stones, however, should not be subjected to much weight until they have dried out.

There is a great abundance of fine sandstone of all colors distributed throughout the United States, so that it is not difficult to get a first-class stone for any building of importance. Most of the sandstones in the Eastern part of the country are either red or brown in color there being no merchantable light sandstones east of Ohio.

159. The following are the best known sandstones in this country, any of which are good building stones:

Connecticut brownstone includes all the dark brown sandstones quarried in the neighborhood of Portland, Conn. It is a handsome dark brown stone, tinted slightly reddish, has a fine even rift, is easy to work, and gives a beautiful surface when rubbed. This stone is decidedly laminated, and the surface will soon peel if the stone is set on edge. When laid on its natural bed, however, it is very durable. This was the first sandstone quarried in the country, and great quantities of it have been used in New York City.

Longmeadow Stone.—This is a reddish-brown sandstone quarried principally at East Longmeadow, Mass. It is an excellent building stone, without any apparent bed, and may be cut any way. It varies from quite soft to very hard and strong stone, and should be selected for good work. It has been largely used throughout the New England States for the past fifteen years.

Potsdam Red Sandstone, from Potsdam, N. Y., is a quartzite and one of the best building stones in the country, being extremely durable and equal to granite in strength. It was used in the buildings of Columbia College, New York City; All Saints Cathedral, in Albany, and in the Dominion Houses of Parliament, in Ottawa, Canada. There are three shades, chocolate, brick-red and reddish-cream.

Hummelstown Brownstone, from Hummelstown, Pa., is a medium fine-grained stone, bluish-brown or slightly purple in color, the upper layers being more of a reddish-brown and much resembling the Connecticut stone. The stone compares very favorably with the other brownstones mentioned, and is in very general use in the principal Eastern cities.

North Carolina, West Virginia and Indiana contain quarries of brownstone which supply the local demand and which are worthy of a wider distribution, particularly that of North Carolina.

Fond du Lac, Minnesota, furnishes a reddish-brown sandstone closely resembling the Connecticut brownstone, but much harder and firmer. "The stone consists almost wholly of quartz cemented with silica and iron oxides."

Ohio Stone.—The finest quality of light sandstone in the United States is quarried in the towns of Amherst, Berea, East Cleveland, Illyria and Independence, Ohio, and is commonly known as Ohio stone or Berea stone. It is a fine-grained, homogenous sandstone, of a very light buff, gray or blue-gray color, and very evenly bedded. The stone is about 95 per cent. silica, the balance being made up of small amounts of lime, magnesia, iron oxides, alumina and alkalies. There is but little cementing material, the various particles being held together mainly by cohesion induced by the pressure to which they were subjected at the time of their consolidation. They are very soft and work readily in every direction, and are especially fitted for carving.

"Unfortunately the Berea stone nearly always contains more or less iron pyrites and needs to be selected with care. Most of the quarries, however, have been traversed by atmospheric waters to such a degree that all processes of oxidation which are possible have been very nearly completed." *

The stone can be furnished in blocks of any desired size and of uniform color. The stone is shipped to all parts of the country, and is in great demand for fine buildings. Mr. H. H. Richardson, the celebrated architect, often used it in contrast with the Longmeadow sandstone for trimmings and decorative effects. The stone contains from about 6 to 8 per cent. of water when first taken from the quarry, and about 4 per cent. when dry. The stone cannot be quarried in winter on account of the splitting of the stone caused by the freezing of the water contained in it. There are some fourteen or fifteen different companies that quarry this stone for the market.

"*The Waverly sandstone* comes from Southern Ohio. This is a fine-grained, homogenous stone of a light drab or dove color, works with facility, and is very handsome and durable. It forms the material of which many of the finest buildings in Cincinnati are constructed, and is, justly, highly esteemed there and elsewhere."†

Ohio is the largest producer of sandstone of any State in the Union.

At *Warrensburg, Mo.*, is quarried a gray sandstone which has been used in many important buildings in Kansas City.

* "Stones for Building and Decoration," pp. 276-277.

† Baker, "Masonry Construction," p. 30.

The Rocky Mountain region also furnishes great quantities of fine sandstones. In Arizona is quarried a very fine-grained chocolate sandstone, which takes a fine edge and is excellently adapted for rubbed and moulded work. A considerable quantity of it is used in Denver, Col., on account of its pleasing color, and it is also shipped east of the Missouri River.

At *Manitou, Col.*, are inexhaustible quarries of a fine red stone, much resembling the Longmeadow stone of Massachusetts, but of a lighter red color. It has no apparent bed and weathers well. It has sufficient strength for ordinary purposes. At *Fort Collins, Col.*, is quarried a much harder and slightly darker stone, which is an excellent stone for almost any purpose. It has sufficient strength for piers and columns, and is hard enough for steps and thresholds. It is much harder to cut than the Manitou stone, and hence is more expensive, but it is more durable. This stone has been shipped as far East as New York City. Colorado also contains an inexhaustible supply of sandstone flagging, admirably adapted for foundations and sidewalks; it is as strong as granite, and may be quarried in slabs of almost any size or thickness.

A red and buff sandstone is quarried at Glenrock, Wyoming, which has been used in Omaha, Nebraska.

California has fifteen quarries of sandstone, the larger number of which are in Santa Clara County. Stanford University is built of a light-colored sandstone quarried at San Jose, Cal.

Owing to the sparsely settled condition of the country and the lack of railroad facilities, the building stones of the Western portion of the United States have been but little developed, but with the building up of the country the quarrying industry will undoubtedly become one of great importance.

160. Lava Stone or Turfa.—Near Castle Rock, in Colorado, is quarried a soft, very light gray and pink stone of volcanic origin, which is commonly called lava stone. It is extremely light in weight, weighing only about 110 pounds per cubic foot, and can be cut with a knife. It weathers better than the soft sandstones, and its color makes it very suitable for rock face ashlar. It is difficult to obtain in large blocks, and is full of clay or air holes and often of invisible cracks, which render it dangerous for use in heavy buildings, but for dwellings it makes a very cheap, durable and pleasing stone. Owing to the small air holes which it contains it does not receive a finished surface, and is most effective when used rock face. There are a great many houses and several public buildings in Denver built of this stone. A similar stone occurs in the vicinity of the Las Vegas Hot Springs, and Albuquerque, New Mexico.

Blue Shale is a variety of sandstone that is dark blue in color, quite dense and hard, and makes a fair material for foundations. As a rule it does not work readily and often contains iron pyrites, which renders it unsuitable for ashlar or trimmings.

The only stone in many localities is a hard, igneous rock, called *trap*, which is suitable for foundations, but cannot be cut easily.

Such stones are only used for local purposes when no other can be obtained except at great expense.

161. Slate.—Although slate is not strictly a building stone, yet it is largely used for covering the roofs of buildings, for blackboards, sanitary purposes, etc., and the architect should be familiar with its qualities and characteristics.

The ordinary slate used for roofing and other purposes is a compact and more or less metamorphosed siliceous clay. Slate stones originated as deposits of fine silt on ancient sea bottoms, which in the course of time became covered with thousands of feet of other materials and finally turned into stone.

"The valuable constituents in slate are the silicates of iron and alumina, while the injurious constituents are sulphur and the carbonates of lime and magnesia."

One of the most valuable characteristics of slate is its decided tendency to split into thin sheets, whose surfaces are so smooth that they lie close together, thus forming a light and impervious roof covering. These planes of cleverage are caused by intense lateral pressure, and are generally at very considerable though varying angles with the ancient bedding.

The most valuable qualities of slate are its strength, toughness and non-absorption.

Strength and Hardness.—From various tests that have been made on the quality of slate, it appears that, in general, the strongest specimens are the heaviest and softest, as also the least porous and corrodible. "The tests for strength and corrodibility are probably those of greatest importance in forming an opinion regarding the value of the slate under actual conditions of service." *

Mr. Mansfield Merriman suggests that specifications should require roofing slates to have a modulus of rupture for transverse strength greater than 7,000 pounds per square inch.

If the slate is too soft, however, the nail holes will become enlarged and the slate will get loose. If it is too brittle the slate will fly to pieces in the process of squaring and holing, and will be easily broken on the roof. "A good slate should give out a sharp metallic ring when struck with the knuckles ; should not splinter under the slater's axe ; should be easily 'holed' without danger of fracture, and should not be tender or friable at the edges."

The surface when freshly split should have a bright metallic lustre and be free from all loose flakes or dull surfaces.

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* Mansfield Merriman in *Stone*, April, 1895.

Color.—The color of slates varies from dark blue, bluish-black and purple to gray and green. There are also a few quarries of red slate. The color of the slate does not appear to indicate the quality. The red and dark colors are generally considered the most effective, and the greens are generally used only on factories, storehouses and buildings where the appearance is not of so much importance.

Some slates are marked with bands or patches of a different color, and the dark purple slates often have large spots of light green upon them. These spots do not as a rule affect the durability of the slate, but they greatly detract from its appearance.

As a rule the dark color of slate, particularly that of the slates of Maine and Pennsylvania, appears to be due to particles of carbonaceous matter contained in the slate.

"The red slates of New York are made up of a ground mass of impalpable red dust in which are imbedded innumerable quartz and feldspar particles."

Absorption.—A good slate should not absorb water to any perceptible extent, and if a slate is immersed in water half its height the water should not rise in the upper half; if it does it shows that the slate is not of good quality.

"If, upon breathing upon a slate, a clayey odor be strongly emitted, it may be inferred that the slate will not weather."

Grain.—A good slate should have a very fine grain, and the slates should be cut lengthways of the grain, so that if a slate breaks on the roof it will not become detached, but will divide into two slates, each held by a nail.

Market Qualities.—The market qualities of slate are classed according to their straightness, smoothness of surface, fair, even thickness, and according to the presence or absence of discoloration.

Uses.—The principal use of slate is for roofing purposes, but it is also used for billiard tables, mantels, floor tiles, steps, flagging, fittings for toilet rooms, and for school blackboards.

162. Distribution and Varieties of Slate.—The distribution of the slate industry among the different States in 1890 is best shown by the following figures, which give the value of the product:

Pennsylvania, $2,011,776; Vermont, $838,013; Maine, $214,000; New York, $130,000; Maryland, $110,008; Virginia, $85,079; Georgia, $15,330; Michigan, $15,000; California, $13,889; New Jersey, $10,985; Arkansas, $240.

Slates are classified in the trade, however, by the name of the region in which they are quarried, some regions extending into two

or more States, while several regions are contained in the State of Pennsylvania. The product from each region is more or less distinctive from that of other regions. The more important producing regions are:

	Number of Quarries.	Product.
Vermont and New York region	76	$968,616
Bangor region, Pennsylvania	20	707,162
Lehigh region, Pennsylvania	45	690,432
Pen Argyl region, Pennsylvania	17	393,030
Maine region	4	214,000
Northampton hard-vein region, Pennsylvania	18	184,595
Peach Bottom region, Maryland and Pennsylvania	9	146,565
Virginia region	3	85,079

The slates of the Bangor, Pen Argyl and Lehigh regions and the Northampton hard veined slates are found in the extensive slate formation known as the Hudson River Division of the lower Silurian deposits, while the slate formations of Vermont and New York, Maine and the Peach Bottom region, probably belong to the Cambrian Division, whose place in the geological series is lower and older than the Silurian rocks.

"The slates of the Cambrian formation are usually regarded as better in respect to strength and weathering qualities than those of the Silurian age, the market price of some varieties of the former being, indeed, more than double that of the common kinds of the latter."

Vermont and New York Region.—In the western portion of Vermont are extensive quarries of slate, the product being used for all the different purposes for which the material is adapted.

The stone is soft and uniform in texture, and can be readily planed or sawed with a circular steel saw like wood.

The slates from this region vary greatly in color, and are classified and sold under the following names:

Sea-green, unfading green, uniform green, bright green, red, bright red, purple, variegated and mottled.

The true sea-green slate is found only in this State, but it fades and changes color badly.

Red Slate.—Nearly all the red slate used in the United States is quarried in the neighborhood of Granville, near the Vermont line, in New York State. "The slates of this formation are of a brick-red and green color, both varieties often occurring in the same quarry." The slate is of good quality and is almost entirely used for roofing purposes, its color making it especially desirable for fine residences and public buildings. Owing to the limited quantity, this slate brings about three times the price of the dark slates.

Maine Region.—The quarries in this region are located at Monson, Blanchard and Brownville, Piscataquis County. The stone is of a blue-black color, of excel-

lent quality, being hard, yet splitting readily into thin sheets with a fine surface. They are not subject to discoloration, and give forth a clear ringing sound when struck. The Brownville slate is said to be the toughest slate in the world. Slate from this quarry, after fifty years' exposure, looks as bright and clean as when new.

The Maine quarries furnish nearly all the black slates used in New England. The product is also extensively used for slates, blackboards and sanitary purposes.

163.—

Pennsylvania Slates.—*Bangor Region.*—This region is entirely within Northampton County, and is the most important, in point of production, in the country. The principal quarries are at Bangor, East Bangor and Slatington. The color is a uniform dark blue or blue-black. This slate is used very extensively for blackboards and school slates, as well as for roofing purposes. Average modulus of rupture, 9,810 pounds.

The *Lehigh region* includes Lehigh County entire and a few quarries in Berk and Carbon Counties and opposite Slatington in Northampton County. The product is similar to that of the Bangor region.

Pen Argyl region embraces quarries at Pen Argyl and Wind Gap in Northampton County.

The *Northampton hard-vein region* includes the Chapman, Belfast and other quarries, all in Northampton County. This region is distinguished on account of the extreme hardness of the slate as compared with that produced in other regions of the State. The product is considered as the best of the Silurian slates, its extreme hardness being generally considered as an advantage to the slate, rendering it durable and non-absorptive. It is especially suitable for flagging. Average modulus of rupture, about 8,480 pounds.

Peach Bottom Region.—The celebrated "Peach Bottom Slate" is taken from a narrow belt scarcely 6 miles long and a mile wide, extending across the southeastern portion of York County and into Hartford County, in Maryland. The stone is tough, fine and moderately smooth in texture, blue-black in color, and does not fade on exposure, as has been proven by seventy five years' wear on the roofs of buildings. It also ranks very high for strength and durability, and is generally considered equal, if not superior, to any slate in the country. The average modulus of rupture of twelve specimens was 11,260 pounds, the lowest value being 8,320 pounds.

The northern peninsula of Michigan contains an inexhaustible supply of good roofing slate, and extensive quarries have been opened about 15 miles from L'Anse and about 3 miles from Huron Bay. "The stone here is susceptible of being split into large, even slabs of any desired thickness, with a fine, silky, homogenous grain, and combines durability and toughness with smoothness. Its color is an agreeable black and very uniform."*

A good blue-black roofing slate is quarried in *Bingham County*, Virginia, which bids fair to supplant other slates in that section of the country.

Quarries in Polk County, *Georgia*, furnish most of the roofing slates for Atlanta and neighboring towns.

Good roofing slate is also known to occur in California, Colorado and Dakota, but the first State mentioned is the only one in which quarries have yet been opened.

* "Stones for Building and Decoration," p. 302.

164. Soapstone.—Although not properly a building stone, soapstone is used more or less in the fittings of buildings, especially for sinks and wash trays, and for the linings of fireplaces.

Soapstone is a dark bluish-gray rock, composed essentially of the mineral talc.

The stone is soft enough to be cut readily with a knife, or even with the thumb nail, and has a decided soapy feeling, hence its name.

Although so soft, this stone ranks amongst the most indestructible and lasting of rocks. At present its chief use is in the form of slabs about $1\frac{1}{4}$ inches thick, for stationary washtubs and sinks, for which it is one of the best materials. Soapstone also offers great resistance to heat, and is often used for lining fireplaces.

At one time it was extensively used in New England in the manufacture of heating stones. Considerable quantities of powdered soapstone are used for making slate pencils and crayons, as a lubricant for certain kinds of machinery, and in the finishing coat on plastered walls.

The principal quarries producing block stone are situated in the States of New Hampshire, Vermont and Pennsylvania.

The State of North Carolina produces most of the powdered soapstone, which is quarried in small pieces and ground in a mill.

SELECTION OF BUILDING STONES.

165. The selection of a stone for structural purposes is a matter of the greatest importance, especially when it is to be used in the construction of large and expensive buildings. The cities of Northern Europe are full of failures in the stones of important structures, and even in the cities of the Northern portion of the United States the examples of stone buildings which are falling into decay are only too numerous.

"The most costly building erected in modern times—the Parliament House in London—was built of a stone taken on the recommendation of a committee representing the best scientific and technical skill of Great Britain. The stone selected was submitted to various tests, but the corroding influences of a London atmosphere were overlooked. The great structure was built (of magnesian limestone), and now it seems questionable whether it can be made to endure as long as a timber building would stand, so great is the effect of the gases of the atmosphere upon the stone." *

* Baker in "Masonry Construction," p. 4.

Stone should be studied with reference to its hardness, durability beauty, chemical composition, structure and resistance to crushing.

166. Climate.—In selecting a building stone the climate, together with the location, with especial reference to the proximity to large cities and manufacturing establishments, should be first considered. There is many a porous sand or limestone which could endure an exposure of hundreds of years in a climate like that of Florida, New Mexico, Colorado or Arizona, which would be sadly disintegrated at the end of a single season in one of the Northern States. The climate of our Northern and Eastern States, with an annual precipitation of some 39 or 40 inches and a variation in temperature sometimes reaching 120°, is very trying on stonework, and unless a stone is suited to the conditions in which it is placed, there are few materials more liable to decay and utter failure.

167. Color.—The great governing point with an architect in selecting a building stone is generally the color. This again is limited to a choice between those stones which come within the limit of cost, and should be finally overruled by the question of durability. The architect is too apt to think that if a building cannot be pleasing both in form and color it had better not be built at all, but he should keep in mind not only how the building will look when just completed, but how it will appear at the end of a few years, and, again, at the end of half a century. It is better that the colors be a little harsh and inharmonious at first, if durability is gained thereby, than to use the most pleasing color only to see it entirely changed at the end of a year, and crumbling in pieces at the end of a decade.

A durable stone of any color generally tones down and becomes more pleasing at the end of a few years, while one that is not durable and permanent in color very soon becomes an eyesore.

In the country and small towns where there is no manufacturing, and where little bituminous coal is used, light-colored stones may be used with the prospect of their color remaining unchanged ; but in large cities and in manufacturing towns, particularly those where bituminous coal is the principal fuel, light stones should be avoided, and for such localities a red or brown siliceous sandstone is the most enduring and permanent, and next to this comes granite.

In a city like Chicago, the darker the stone used the more permanent will be its color (that is, in the central portion of the city), as both brick and stone assume a dirty, dark bronze color in a few years, and in such localities delicate colors and fine carving are out of place.

In climates like that of Colorado, Arizona and New Mexico, where there is a very bright sun and almost no rain, the light stones, and particularly marbles, are most effective, as the shadows on such stones are very marked, and all kinds of ornament are made much more prominent than on red or dark stones, and any compact stone will last for centuries above the ground.

As a rule, all else being equal, the stone which holds its native color best will be most beautiful in a building, and of the stones which change color, that will be most desirable which changes least and evenly.

168. Durability.—Naturally the durability of a stone is of the first importance, for unless the stone will last a reasonable length of time, the money spent on the structure will be largely wasted, and all public buildings should be built of material that is practically imperishable.

The following table, taken from the Report of the Tenth Census, 1880, Vol. X., p. 391, gives the number of years that different stones have been found to last in New York City, without discoloration or disintegration to the extent of necessitating repairs:

Coarse brownstone	5 to 15
Fine laminated brownstone	20 to 50
Compact brownstone	100 to 200
Bluestone (sandstone), untried	Probably centuries
Nova Scotia sandstone, untried	Perhaps 50 to 200
Ohio sandstone (best siliceous variety),	Perhaps from one to many centuries
Coarse fossiliferous limestone	20 to 40
Fine oolitic (French) limestone	30 to 40
Marble, coarse dolomite	40
Marble, fine dolomite	60 to 80
Marble, fine	50 to 100
Granite	75 to 200
Gneiss	50 years to many centuries

There are many circumstances and conditions, aside from the quality of the stone, that affect the durability of exposed stonework, the more important of which are heat and cold, composition of the atmosphere, position of the stone in the building, and manner of dressing the stone.

169. Heat and Cold.—The most trying conditions to which a building stone is subject are the ordinary changes of temperature which prevail in the Northern and Eastern States. "Stones, as a rule, possess but a low conducting power and slight elasticity. They

are aggregates of minerals, more or less closely cohering, each of which possesses degrees of expansion and contraction of its own. As temperatures rise each and every constituent expands more or less, crowding with resistless force against its neighbor; as the temperatures decrease a corresponding contraction takes place. Since the temperatures are ever changing, often to a considerable degree, so, within the mass of the stone, there is continual movement among its particles. Slight as these movements may be they can but be conducive of one result, a slow and gradual weakening and disintegration." * This is supposed to be the chief cause of the disintegration of granites.

There are several examples of old stonework in New York City that have begun to decay on the south and west sides, where the sun shines the longest, but not on the north and east. The effects of moderate temperatures upon stones of ordinary dryness are, however, slight when compared with the effects of freezing upon stones saturated with moisture. The pressure exerted by water passing from a liquid to a solid state amounts to not less than 138 tons to the square foot; and it is, therefore, evident that any porous stone exposed to heavy rains and a temperature several degrees below the freezing point must be seriously damaged by a single season's exposure. It is also evident that the more *porous* a stone the greater will be the deterioration, and as sandstones are the most porous of all building stones they suffer the most from this cause and granites the least, hence granite is the best stone for a base course or underpinning. [For the effect of absorption on the durability of stones see Section 177.]

170. Stone Set on Bed.—When a stone is built into the walls of a building in such a way that the natural layers of the stone are vertical, or on edge, the water penetrating the stone and freezing causes the surface of the stone to exfoliate or peel off much quicker and to a greater extent than it would if the stone had been laid with its natural bed horizontal.

Stones that are so situated in a building that the rain will strike and wash over them, such as sills, belt courses, etc., also decay sooner than the ashlar forming the face of the wall, and should be of the most durable material.

171. Atmospheric Action.—The chemical action of the gases of the atmosphere, when brought by rain in contact with the surface

* "Stones for Building and Decoration," p. 353.

of certain stones, seriously affects their durability. The most important changes produced by these agencies are oxidation and solution.

Oxidation.—The process of oxidation is, as a rule, confined to those stones which contain some form of iron, and particularly that known as pyrite. If the iron exists in the latter shape it generally combines with the oxygen of the air, forming the various oxides and carbonates of iron, such as are popularly known as "rust."

"If the sulphide occurs scattered in small particles throughout a sandstone the oxide is disseminated more evenly through the mass of the rock, and aside from a slight yellowing or mellowing of the color, as in certain Ohio sandstones, it does no harm. Indeed, it may result in positive good, by supplying a cement to the individual grains and thus increasing the tenacity of the stone." *

If the pyrite exists in pieces of any size, however, it is almost sure to oxidize and stain the stone so as to ruin its appearance, especially if it is of a light color.

In all other than sandstones the presence of any pyrite is a very serious defect, as it is almost sure to rust the stone and may also render it porous and more liable to the destructive effects of frost.

Solution.—The worst effect of the action of the gases of the atmosphere in connection with rain is in dissolving certain constituents of stones, thereby causing their decomposition. Pure water alone is practically without effect on all stones used for building, but in large cities, and particularly those in which a great deal of coal is consumed, the rain absorbs appreciable quantities of sulphuric, carbonic and other acids from the air and conveys them into the pores of the stone, where they very soon destroy those stones whose constituents are liable to be decomposed by such acids.

Carbonate of lime and carbonate of magnesia, the principal constituents of ordinary marbles, limestones and dolomites, are particularly susceptible to the solvent action of these acids, even when they are present only in very minute quantities, and on this account these stones are extremely perishable in large cities and manufacturing towns. Of course in dry climates the acids are not conveyed into the stone to any great extent, and the stones last much longer than in a damp climate. The less absorbent a stone is the less will be the solvent action of the acids, and the longer the stone will last. Dolomites are in this respect more durable than limestones.

Sandstones, whose cementing material is composed largely of iron or lime, are also subject to rapid decay through the solvent action of

* "Stones for Building and Decoration," p. 360.

the acidulated rains. The feldspars of granites and other rocks are also susceptible to the same influence, though in a less degree.

172. Method of Finishing.—This also has a great deal to do with the durability of a stone. As a rule, the less jar from heavy pounding that the surface is subjected to, the more durable will be the surface, for the reason that the constant impact of the blows tends to destroy the adhesive or cohesive power of the grains, and thus renders the stone more susceptible to atmospheric influences. This applies particularly to granites and limestones. Only granites and the hardest sandstones should be pene or bush hammered ; all others, if dressed, should be cut with a chisel. Sandstones may afterward be finished with a crandal, if desired. For granites a rock-face surface would probably prove most durable, since the crystalline facets thus exposed are best fitted to shed moisture and the natural adhesion of the grains has not been disturbed. For all other stones, however, a smoothly sawn, rubbed or polished surface seems best adapted to a variable climate.

173. Strength.—Whenever a stone is to be used for foundations, piers, lintels, bearing stones, etc., its strength should be considered, and if it has not been demonstrated by practical use under similar circumstances, cubes of the stone about 6 inches on a side should be carefully tested for the crushing strength. If the stone has all the appearance of a first-class stone of its kind, its strength may be assumed to be equal to the average strength of stones of that kind. The safe working strength for piers, etc., should not exceed one-tenth of the crushing strength. Tables giving the crushing strength of many well-known stones and the safe working strength for stone masonry are given in the appendix.

The method in which a stone is quarried sometimes has much to do with its strength. If the stone is quarried by means of explosives the stone may contain minute cracks, which cannot be discovered until the stone receives its load, when their presence is unpleasantly manifested. Such an occurrence could only take place in some stone like lava or conglomerates. The cracking and splitting of stones in buildings is often due more to *imperfect setting* than to lack of strength in the stone. Any stone that will meet the requirements for durability will have sufficient strength for all purposes, except in the positions mentioned above.

Hardness.—For many purposes the hardness of a stone must be considered, as when it is to be used for steps, door sills, paving, etc.

Granite, quartzite, or siliceous sandstone, and bluestone are the best stones for this purpose.

Cheapness.—This often has more to do with the choice of a building stone by the owner than the architect could wish. The cost of the stone when cut depends not only upon the cost of the rough stone delivered at the site, but also upon the ease with which the stone may be worked ; whether the stone is to be smooth or rock face ; plain or moulded ; and also to some extent upon its weight. One stone may be cheaper than another in the rough, but the extra labor of cutting may make it the most expensive when put in the wall. The heavier a stone is the greater will be the cost of setting and transportation.

174. Fire Resistance.—The ability of a stone to withstand the action of fire is often of much consequence, especially when it is exposed to fire risks on all sides, as is the case with most business blocks. Of the different kinds of stone used for building the compact, fine-grain sandstones withstand the action of fire the best ; limestones and marbles suffer the worst (becoming calcined under an intense heat) and granites are intermediate. The best sandstones generally come out uninjured, except for the discoloration caused by smoke. Granites do not collapse, but the face of the stone generally splits off and flies to pieces, often with explosive violence.

175. New Stones.—If, in selecting a building stone, it is deemed advisable to use a stone from a new quarry, and the weathering qualities of the stone have not been tested by actual use in buildings, the architect should insist upon a chemical and microscopic test of the stone by an expert to see if there is anything in the composition or structure of the stone that would render it unsuited for building purposes, and if the report is favorable, and the stone meets the tests described in the following sections, he may then use it with a free conscience.

An architect cannot be too careful about using a new stone, or one that has not been used under similar circumstances, and whenever he is obliged to use such a stone he should take pains to obtain as much information in regard to it, from all practical sources, as possible.

The writer has known of a case in which a stone, which had for a long time been used for making ashlar, was used in the piers under a seven-story building, and the piers commenced to crack under only about one-one-hundredth part of the breaking strength of the stone as given in a published report of tests on the strength of stone, and it cost nearly $200,000 to repair the damage and substitute other

stone. The failure of the stone (which was a lava stone) was supposed to be due to fine cracks produced in blasting out the stone from the quarry.

It will not always do, either, to rely upon the past reputation of a stone for durability, as the quality of building stones from the same quarry often differ.

TESTING OF BUILDING STONES.

176. Every stone intended for building purposes that does not come from some well-known quarry should be tested by chemical analysis, and the results compared with the analyses of well-known stones of the same kind, and if found to differ materially in constituents soluble in water or attached by sulphuric or carbonic acids, they should be rejected ; the presence of iron pyrites should also lead to the rejection of the stone, if intended for external use. If the building is one of importance the architect should insist on the owners getting the opinion of some expert chemist or mineralogist on the durability and weathering qualities of the stone.

As a rule, however, most buildings are now built from stone taken from well-known quarries, whose weathering qualities have been proved, so that if the quality is equal to the best that the quarry will supply the stone will prove all that was expected of it. The fact, however, that certain quarries have furnished good material in the past is no guarantee of the future output of the entire quarry. This is especially true regarding rocks of sedimentary origin, as the sand and limestones, different beds of which will often vary widely in color, texture, composition and durability, though lying closely adjacent. In many quarries of calcareous rocks in Ohio, Iowa and neighboring States, the product is found to vary at different depths, all the way from a pure limestone to magnesian limestones and dolomite, and in many cases an equal variation exists in point of durability.*

The architect should, therefore, make a careful examination of the stone as it is delivered on the ground, or in the yard before it is cut, to see that the quality of the stone is up to the standard, and in large buildings in which a great quantity of stone will be required, it will be advisable to visit the quarry and determine from which part of the quarry the stone shall be taken.

The following rules and tests will enable one to judge if the stone is of a good quality and likely to prove durable :

* "Stones for Building and Decoration," p. 380.

Compactness.—As a general rule, in comparing stones of the same class, the least porous, most dense and strongest will be the most durable in atmospheres which have no special tendency to attack the constituents of the stone. A good building stone should also give out a clear, ringing sound when struck with a hammer.

Fracture.—A fresh fracture, when examined through a powerful magnifying glass, should be bright, clean and sharp, with the grains well cemented together. A dull, earthy appearance indicates a stone likely to decay.

177. *Absorption.*—One of the most important tests for the durability of stone is that of the porosity, or degree with which the stone absorbs moisture, since, other things being equal, the less moisture a stone absorbs the more durable it will be.

To determine the absorptive power the specimen should be thoroughly dried at about 100° F. and carefully weighed ; it must then be soaked for at least twenty-four hours in pure water ; when removed from the water, the surface allowed to dry in the air and then weighed. The increase in weight will be the amount of water absorbed, and will stand, although not absolutely correct, as an expression of the stone's absorptive power. This test is extremely simple, and when done with care should give very practical results.

Any stone which will absorb 10 per cent. of its weight of water during twenty-four hours should be looked upon with suspicion until, by actual experiment, it has shown itself capable of withstanding, without harm, the different effects of the weather for several years. Half of this amount may be considered as too large when the stone contains any appreciable amount of lime or clayey matter.*

The porosity of a stone also has influence upon its appearance when in the building.

A non-absorbent stone is washed clean by each heavy rain, and its original beauty is retained, while a porous stone soon fills with dirt and smoke and looks little better than a wall plastered with cement. Even in stones for interior decoration absorption should not be overlooked, as ink, oils or drugs may ruin expensive furnishings if the stone is porous.

178. *Acid Test.*†—Simply soaking a stone for some days in dilute solutions containing 1 per cent. of sulphuric acid and of hydrochloric acid will afford a rough idea as to whether it will stand a town atmosphere. A drop or two of acid on the surface of the stone will create

* "Stones for Building and Decoration," p. 371.

† "Notes on Building Construction," Part III , p. 11.

an intense effervescence if there is a large proportion present of carbonate of lime or carbonate of magnesia.

Test for Solution.—The following simple test is useful for determining whether a stone contains much earthy or mineral matter easy of solution :

Pulverize a small piece of the stone with a hammer, put the pulverized stone into a glass about one-third full of clear water, and let the particles remain undisturbed at least half an hour. Then agitate the water and broken stone by giving the glass a circular motion with the hand. If the stone be highly crystalline, and the particles well cemented together, the water will remain clear and transparent, but if the specimen contains uncrystallized earthy powder, the water will present a turbid or milky appearance in proportion to the quantity of loose matter contained in the stone.

SEASONING OF STONE.

179. All stone is better for being exposed in the air until it becomes dry before it is set. This gives a chance for the quarry water to evaporate, and in nearly all cases renders the stone harder, and prevents the stone from splitting from the action of the frost.

Many stones, particularly certain varieties of sandstone and limestone, that are quite soft and weak when first quarried acquire considerable hardness and strength after they have been exposed to the air for several months. This hardness is supposed to be caused by the fact that the quarry water contained in the stone holds in solution a certain amount of cementing material, which, as the water evaporates, is deposited between the particles of sand, binding them more firmly together and forming a hard outer crust to the stone, although the inside remains soft, as at first. On this account the stone should be cut soon after it is taken from the quarry, and if any carving is to be done it should be done before the stone becomes dry, otherwise the hard crust will be broken off and the carving will be from the soft interior, and hence its durability much lessened.

PROTECTION AND PRESERVATION OF STONEWORK.

180. There are a great many preparations that have been used for preventing the decay of building stones, but all are expensive, and none have proved very satisfactory.

Paint.—The substance most generally used for preserving stonework is lead and oil paint. This is effectual for a time, but the paint is destroyed by the atmospheric influences, and must be renewed

every three or four years. The paint also spoils the beauty of the stone.

The White House at Washington is built of a porous red sandstone, which has been painted white for many years.

Oil.—Boiled linseed oil is sometimes used on stonework, but it always discolors a light-colored stone, and renders a dark-colored one still darker. "The oil is applied as follows: The surface of the stone is washed clean, and, after drying, is painted with one or more coats of boiled linseed oil, and finally with a weak solution of ammonia in warm water. This renders the tint more uniform. This method has been tried on several houses in New York City, and the waterproof coating thus produced found to last some four or five years, when it must be renewed. The preparation used in coating the Egyptian obelisk in Central Park is said to have consisted of paraffine containing creosote dissolved in turpentine, the creosote being considered efficacious in preventing organic growth upon the stone. The melting point of the compound is about 140° F. In applying, the surface to be coated is first heated by means of especially designed lamps and charcoal stoves, and the melted compound applied with a brush. On cooling it is absorbed to a depth dependent upon the degree of penetration of the heat. In the case of the obelisk about $\frac{1}{2}$ inch." *

A soap and alum solution has also been used for rendering stone waterproof, with moderate success.

Ransome's Process.—This consists in applying a solution of silicate of soda or potash (water glass) to the surface of the stone, after it has been cleaned, with a whitewash brush until the surface of the stone has become saturated. After the stone has become dry a solution of chloride of calcium is applied freely so as to be absorbed with the silicate into the structure of the stone. The two solutions produce by double decomposition an insoluble silicate of lime, which fills the pores of the stone and binds its particles together, thus increasing both its strength and weathering qualities. This process has been used to a considerable extent in England, and is perhaps the most successful of all applications. The process of applying the solutions is more fully described in "Notes on Building Construction," Part III., p. 78.

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* "Stones for Building and Decoration," pp. 399-400.

CHAPTER VI.

CUT STONEWORK.

181. To properly lay out, detail and specify the stonework in a building, it is necessary to have a thorough knowledge of the different tools and processes employed in cutting and dressing the stone and of the different ways in which stone is used for walls, ashlar and trimmings.

The following description of different classes of work, supplemented by critical observation in the stone yard and at the building, should give one a good idea of the ordinary methods and practices employed in this country:

Stonework, such as is used in the superstructure of buildings, may be divided into three classes: *Rubble*, *Ashlar* and *Trimmings*.

182. **Rubble Work** is only used for exterior walls in places where suitable stone for cutting cannot be cheaply obtained. There are some localities which furnish a cheap, durable stone that cannot

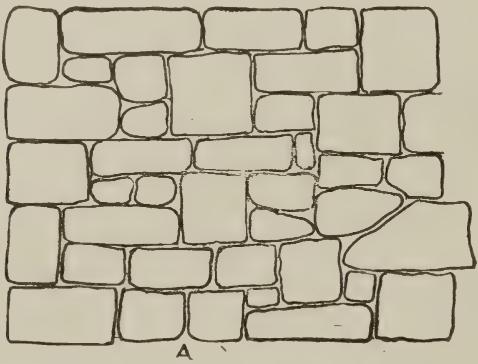

Fig. 60—Rubble, Undressed, Laid at Random.

be easily cut, such as the conglomerates and slate stones. These stones generally split so as to give one good face, and may be used with good effect for walls, with cut stone or brick trimmings.

Fig. 60 shows the usual method of building a rubble wall above ground. After the wall is up the joints are generally filled flush with

mortar of the same color as the stone, and a raised false joint of red or white mortar stuck on, to imitate ashlar. Such work should be specified to be laid with beds and joints undressed, projections knocked off and laid at random, interstices to be filled with spalls and mortar. If a better class of work is desired, the joints and beds should be specified to be hammer-dressed.

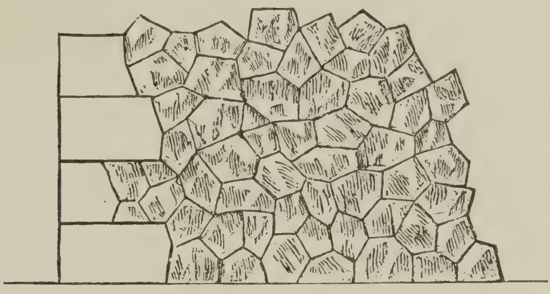

Fig. 61.—Random Rubble with Hammer-dressed Joints and no Spalls on Face.

Fig. 61 shows a kind of rubble work sometimes used for buildings, which is quite effective for suburban architecture. It should be specified to have hammer-dressed joints, not exceeding $\frac{1}{2}$ or $\frac{3}{4}$ of an inch, and no spalls on face. This is generally expensive work.

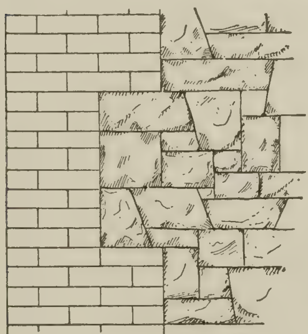

Fig. 62.

Fig. 62 shows a rubble wall with brick quoins and jambs.

Occasionally small boulders or field stone are used for the walls of rustic buildings. In such case the wall should be quite thick, with a backing of split stone, to hold the boulders, and the exact manner in which the wall is to be built should be specified. There are several kinds of rubble used in engineering work, but the above are about the only styles used in buildings.

183. Ashlar.—The outside facing of a wall, when of cut stone, is called *ashlar*, without regard to the way in which the stone is finished. Ashlar is generally laid either in continuous courses, as in Figs. 63 and 64, or in broken courses, as in Fig. 68; or without any continuous horizontal joints, as in Figs. 65 and 66, which represent *broken ashlar*. Coursed work is always the cheapest when stones of a given

size can be readily quarried, as is usually the case with sand and limestones. The cheapest ashlar for most stones is that which is cut into 12-inch courses, with the length of the stones varying from 18 to

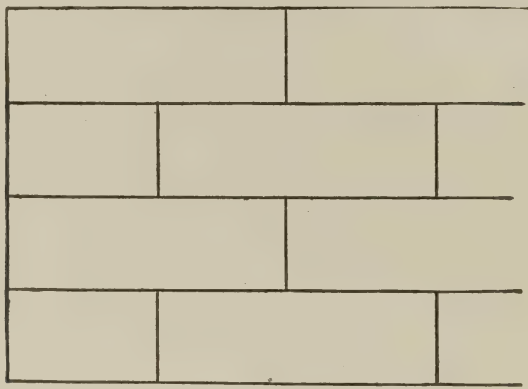

Fig. 63.—Coursed Ashlar.

24 inches. When the stones are cut 30 inches to 3 feet in length, and with the end joints plumb over each other, as in Fig. 63, the cost is considerably increased, and if this kind of work is desired it should be particularly specified.

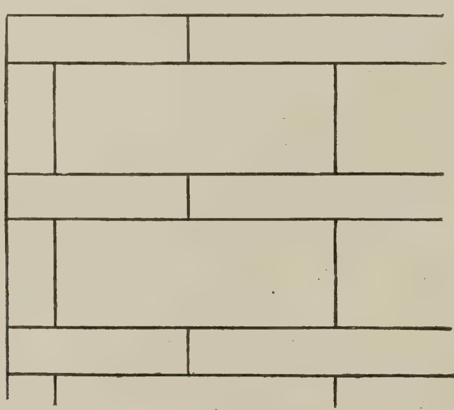

Fig. 64.—Coursed Ashlar.

Fig. 63 is regular coursed ashlar, each course — inches in height, and with plumb bond. When the courses of stone are of different heights it is called irregular coursed ashlar.

A form of ashlar now much used is that shown in Fig. 64, in which a wide and narrow course alternate with each other. Six and 14 inches make good heights for the courses.

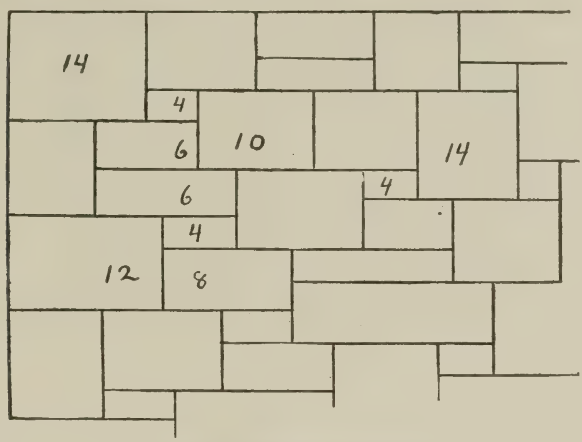

Fig. 65.—Broken Ashlar (Six Sizes).

Fig. 69 shows regular coursed ashlar, with rustic quoins and plinth, which is much used in Europe.

184. Broken Ashlar.—When stones of uniform size cannot be

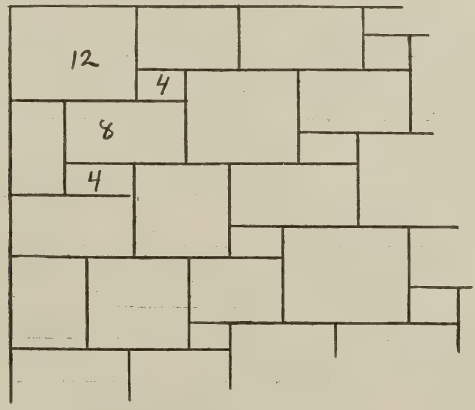

Fig. 66.—Broken Ashlar (Three Sizes).

cheaply quarried the stone may be used to better advantage in broken ashlar, but it takes longer to build it, and, as a rule, broken ashlar costs considerably more than coursed ashlar. This style of

work is generally considered the most pleasing, and, when done with care, makes a very handsome wall, as shown by the half-tone illustration, Fig. 67. It is generally only used for rock-face work. To have

Fig. 67.—Broken Ashlar.

the best appearance no horizontal joint should be more than 4 feet long, and several sizes of stone should be used. Broken ashlar can be more quickly laid, and at less expense, if the stone is cut to certain heights in the yard, so that only one end joint need be cut at the building.

Fig. 68.—Random Coursed Ashlar.

Fig. 65 is made up of stones cut 4, 6, 8, 10, 12 and 14 inches in height, while in Fig. 66 only three sizes of stones have been used. Fig. 65 would probably be the more pleasing of the two if executed.

In specifying broken ashlar the height of the stone to be used should be specified. Broken ashlar is sometimes arranged in courses from 18 to 24 inches high, as in Fig. 68, when it is called random coursed ashlar. It looks very well in piers.

185. Quoins and Jambs.—The stones at the corner of a building are called the quoins, and these are often emphasized, as in Figs. 61 and 69. They should always be equal in size to the largest of the stones used in the wall. The stones at the side of a door or window opening are called jambs. Fig. 70 represents cut stone window jambs in a rubble wall. A portion of the jamb stones should extend through the wall to give a good bond.

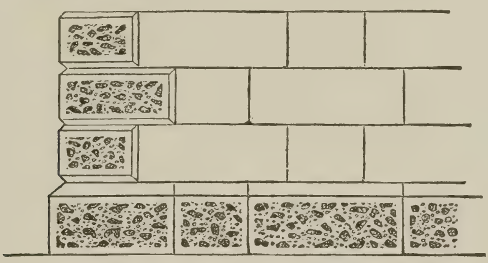

Fig. 69.—Regular Coursed Ashlar.

In rubble walls the quoins and jambs are often built of brick, as shown in Fig. 62.

All ashlar work should have the bed joints perfectly straight and horizontal, and the vertical joints perfectly plumb, or the appearance will be greatly marred.

Trimmings.—This term is generally used to denote all mouldings, caps, sills and other stonework, except ashlar. The trimmings may be pitched off on their face, but all washes, soffits and jambs should be cut or rubbed.

STONECUTTING AND FINISHING.

186. That the architect may specify correctly the way in which he wishes the stone finished in his buildings, it is necessary that he be familiar with the tools used in cutting, and the technical names applied to different kinds of finish.

Stonecutting Tools.—There are several kinds of hammers used by masons in dressing rubble, and also a variety of tools used in quarrying, but as they are not used in working the finished stone they will not be described.

The Axe or Pean Hammer, Fig. 71, has two cutting edges. It is used for making drafts or margin lines around the edge of the stones, and for reducing the faces to a level. It is used after the point on granite and other hard stones.

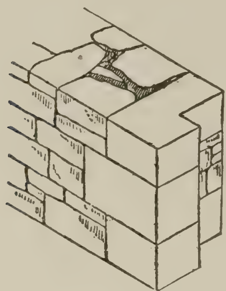

Fig. 70.

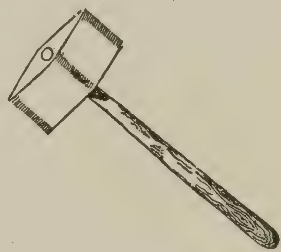

Fig. 71.—Axe or Pean Hammer.

The Tooth Axe, Fig. 72, has its cutting edges divided into teeth, the number of which varies with the kind of work required. It is used for reducing the face of sandstones to a level, ready for the crandall or tool. It is not used on granites and hard stones.

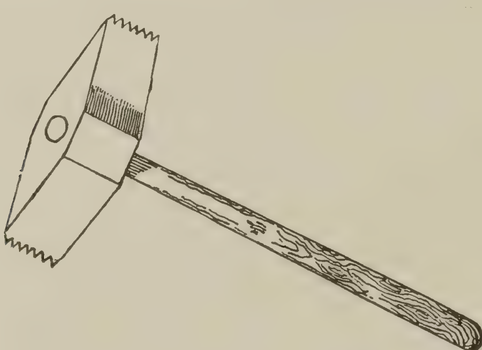

Fig. 72.—Tooth Axe.

The Bush Hammer, Fig. 73, is a square hammer, with its ends (from 2 to 4 inches square) cut into a number of pyramidal points. It is used for finishing the surface of sand and limestones, after the face of the stone has been brought nearly to its place.

The Crandall, Fig. 74, is a malleable iron bar about 2 feet long, slightly flattened at one end, through which is a slot $\frac{3}{8}$ of an inch wide and 3 inches long. Through this slot are passed ten double-

headed points of $\frac{1}{4}$-inch square steel, about 9 inches long, which are held in place by a key. Only one end of the crandall is used, and as the points become dull they can be taken out and sharpened or

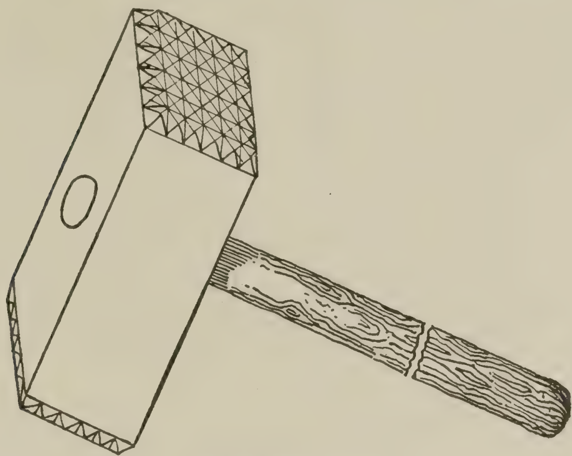

Fig. 73.—Bush Hammer.

the ends reversed. The instrument is used for finishing sandstone after the surface has been prepared by the tooth axe or chisel.

The Patent Hammer, Fig. 75, sometimes called bush hammer, is made of four, six, eight or ten thin blades of steel, ground to an edge and bolted together so as to form a single piece. It is used for fin-

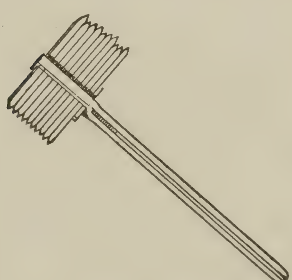

Fig. 74.—Crandall.

Fig. 75.—Patent Hammer.

ishing granite and hard limestones, the fineness of the finish being regulated by the number of blades used.

The Point.—Fig. 76, No. 4, has a sharp point, and is used in breaking off the rough surface of the stone and reducing it to a plane,

ready for the axe, hammer or tool. It is also used to give a rough finish to stone for *broach* work and also for *picked* work. No. 1, Fig. 76, represents the *tooth chisel*, used only on soft stones; No 2 a *drove*, about 2 or 3 inches wide; Nos. 3, 7 and 8 different forms of

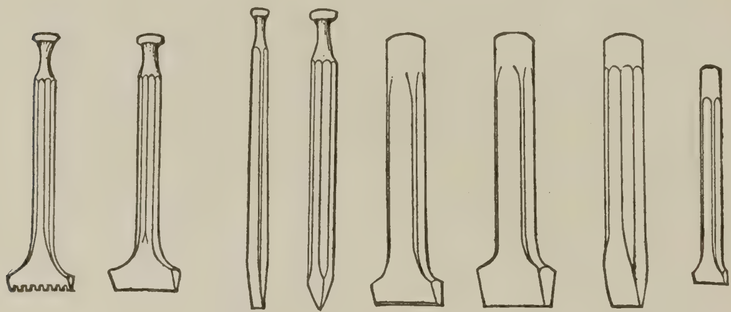

Fig. 76.

chisels used on soft stone. No. 5 is a *tool*, usually from 3½ to 4½ inches wide, used for finishing sandstone, and No. 6 is a pitching chisel, used as in Fig. 77.

187. Different Kinds of Finish.—*Rock-face or pitch-faced* work is shown in Fig. 77, the face of the stone being left rough as it

Fig. 77.—Rock-face or Pitch-face.

Fig. 78.—Rock-face with Draft Line.

came from the quarry, with the joints or edges "pitched off" to a line as shown. The amount of projection of the centre of the stone beyond the plane of the joints should be specified. The ashlar shown in Fig. 67 is "rock-face."

Rock-face with margin lines is the next step toward finishing a stone, and is shown in Fig. 78. The margin (often called draft line)

is cut with a tool chisel in soft stones and with an axe in granite. Sometimes only the angle of the quoins has a draft line, as in Fig. 79, when it is called "angle draft." Rock-face ashlar is naturally cheaper than any kind of dressed ashlar, particularly in granite.

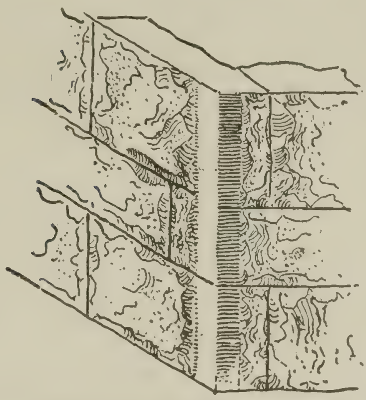

Fig. 79.—Rock-face with Angle Draft.

Broached Work.—The surface of the stone is dressed off to a level surface, with continuous grooves made in it by the point. Fig. 80 shows a stone with margin or draft lines and broach centre.

Pointed Work (Figs. 81 and 82).—When it is desired to dress the face of a stone so that it shall not project more than $\frac{1}{4}$ to $\frac{1}{2}$ inch, and where a smooth finish is not required, as in basement piers, etc., the rock-face is taken off with a point and the surface is *rough* or fine pointed, according as the point is used over every inch or half inch of the stone. The point is used more for dressing hard stones than soft stones.

Tooth-chiseled.—The cheapest method of dressing soft stones is by the tooth chisel, which gives a surface very much like pointed work, only generally not as regular.

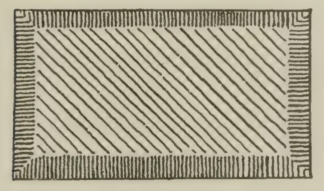

Fig. 80.—Broached with Tooled Margin.

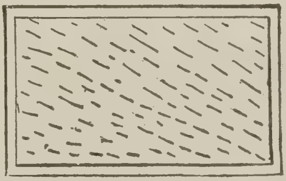

Fig. 81.—Rough Pointed.

Tooled work is done with a flat chisel from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches wide, and the lines are continued clear across the width of the piece, as shown in Fig. 83. When well done it makes a very pretty finish for sandstone and limestone, and especially for moulded work.

Drove work is much like tooled work, but done with a chisel about $2\frac{1}{2}$ inches wide and in rows lengthways of the piece, as shown in Fig. 84. Drove work does not take quite as much time as tooled work, and hence is cheaper, but it does not look as well.

Bush-hammered.—This finish is made by pounding the surface of the stone with a bush hammer, leaving it full of points, as in Fig. 87. It makes a very attractive finish for the harder kinds of sand and limestones, but ought not to be used on soft stones.

Crandalled Work (Fig. 85).—The face of the stone is dressed all over with the crandall, which gives it a fine pebbly appearance when thoroughly done. It makes a sparkling surface for red sandstones,

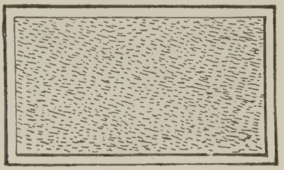

Fig. 82.—Fine Pointed.

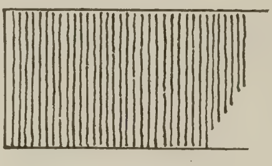

Fig. 83.—Tooled.

and is used more than any other finish in Massachusetts for sandstones. The crandall is not used on granite and other hard stones.

Rubbed.—One of the handsomest methods of finishing sand and limestones is to rub their surfaces until they are perfectly smooth, either by hand, using a smooth piece of soft stone with water and sand for rubbing, or by laying the stone on a revolving bed called a rubbing bed. When the stone is first sawed into slabs rubbing is

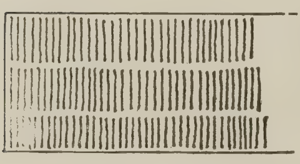

Fig. 84.—Drove Work.

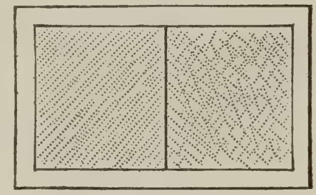

Fig. 85.—Crandalled.

very easily and cheaply done, so that rubbed sandstone ashlar is often as cheap as rock-face work in yards where steam saws are used. The saws leave the stone comparatively smooth and suitable for the top of copings and unexposed places. Granites, marbles and many limestones, when rubbed long enough, take a high polish.

Picked Work.—In this work the face of the stone is first leveled off with the point and then picked all over as though a woodpecker

had picked it. Broken ashlar finished in this way has a very pretty effect, but is quite expensive.

Patent-hammered or Bush-hammered (Fig. 86).—When it is desired to give a finished surface to granite and the hard limestones they are first dressed to a rough surface with the point and then to a medium surface with the same tool, and finally finished with the patent hammer. The fineness of the finish is determined by the number of

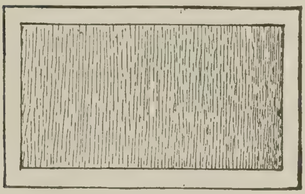

Fig. 86.—Patent-hammered.

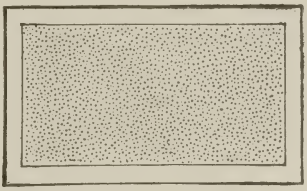

Fig. 87.—Bush hammered.

blades in the hammer, and the work is said to be "six-cut," "eight-cut" or "ten-cut," according as six, eight or ten blades are used. Government work is generally ten-cut. Eight-cut is mostly used for average work, and for steps and door sills six-cut is sufficiently fine. The architect should always specify the number of blades to be used when the work is to be finished with a patent hammer. The same finish may be obtained with the axe, but it requires much more time.

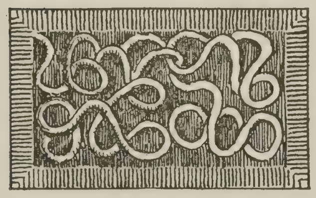

Fig. 88.—Vermiculated.

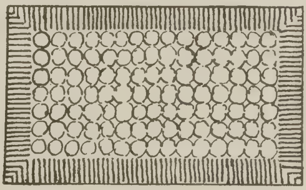

Fig. 89.—Fish Scale.

Vermiculated Work (Fig. 88).—Stones worked so as to have the appearance of having been worked by worms. It is generally confined to quoins and base courses.

Rusticated Work.—This term is now generally used to denote sunk or beveled joints, as in Figs. 69 and 90, although it originally referred to work honeycombed all over on the face to give a rough effect, as shown in Fig. 69.

Fish Scale or Hammered Brass (Fig. 89).—Work made to imitate hammered brass, and done with a tool with rounded corners.

Vermiculated and fish scale work are seldom seen in this country.

188. Laying Out.—If the cost of the stonework must be considered, the architect should ascertain from some reliable local stone dealer the most economical size for the kind of stone he intends to use, and lay out his work accordingly.

Trimmings.—If the stonework consists merely of trimmings for a brick building, the architect or his draughtsman must first ascertain the exact measurement of the bricks as laid in the wall, and the stone should be figured so as to exactly fit in with the brickwork, otherwise

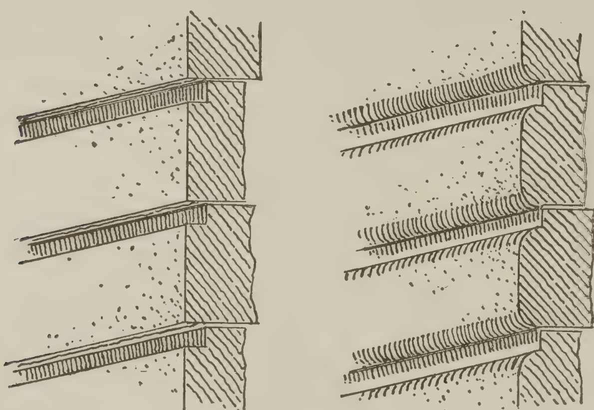

Fig. 90.—Rusticated Joints.

the bricks will have to be split where they come against the stone, thereby greatly marring the looks of the building. Bond stones and belt courses built into a pier must conform exactly to the size of the pier. As it is seldom that the bricks from any two yards are of exactly the same size, the exact size of the bricks that are to be used must be taken, as even a variation of $\frac{1}{4}$ inch often makes bad work.

189. *Drip and Wash.*—Projecting cornices, belt courses and other trimmings should have sufficient depth that they will *balance on the wall*, and all projecting stones should have a *drip* as near the top of the stone as possible, to prevent the water from dripping over the rest of the cornice and down on the wall. Thus in a cornice such as shown in Fig. 91 the stone should be cut at a sharp angle at *A*, so that some of the water may drop off, and there should be a regular drip at *B*, that the water may not run down on the wall. It is a

good idea to cut a drip in all window sills, as shown in Fig. 92. In the summer dust always lodges on a sill or projecting ledge, and when it rains the water washes the dust, which often contains cinders, over the face of the stonework and down on the wall, causing both to become badly streaked and often unsightly.

The architect will find that if he is careful to provide drips on all mouldings and sills his buildings will remain bright and clean for a

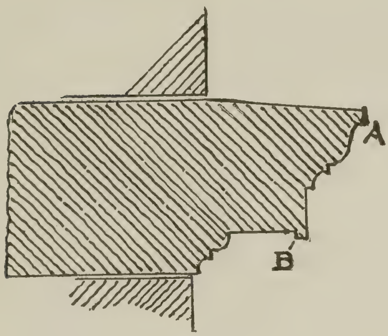

Fig. 91.

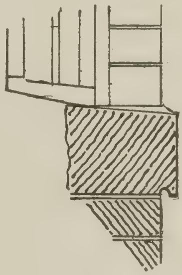
Fig. 92.

much longer time than would otherwise be the case. It is even better to change the profile of the moulding, if necessary, to provide the drip, as the most beautiful moulding looks unsightly when streaked and stained with dirty water.

Washes.—The top of all cornices, belt courses, capitals, etc., should be cut so as to pitch outward from the wall line, as shown in Fig. 91.

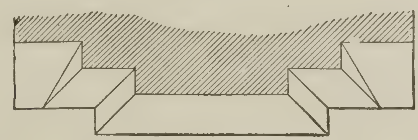
Fig. 93.—Top of Belt Course.

If the top is left level, the rain water falling upon it will, in time, disintegrate the mortar in the joint above and finally penetrate into the wall. Surfaces beveled in this way are called washes.

When the face of a wall is broken with pilasters, or the windows are recessed, the wash on the belt courses should be cut to fit the plan of the wall above, as shown in Fig. 93.

190. Relieving and Supporting Lintels.—[A lintel is the stone which covers a door or window opening, and which, therefore, acts as a beam. They are often designated by stonecutters by the

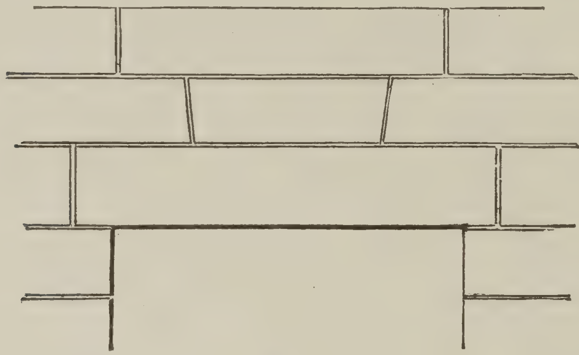

Fig. 94.

term "cap."] When it is necessary to use rather a long lintel in a stone wall the ashlar above the lintel may be arranged so as to relieve the lintel of some of the weight, as shown in Fig. 94. If the wall above the lintel is of brick a relieving arch may be turned, but this generally detracts from the appearance of the building, and the best way to strengthen the lintel, when the length does not exceed 6 feet, is to let it rest on a steel angle bar the full length of the cap, as shown in Fig. 95. When the width of the opening is more than 6 feet the lintel should be supported by steel beams, as shown in Figs 96 and 97. A single beam, as in Fig. 96, may be used where only the weight of the lintel and its load is to be supported, and two or more beams where the whole thickness of the wall and also the floor joist must be supported.

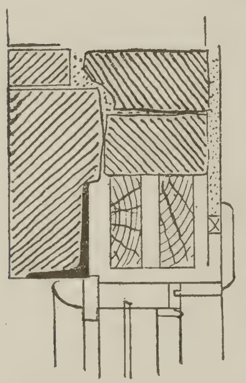

Fig. 95

When the lintel is the full thickness of the wall, and any steel support is undesirable, the strength of the lintel may be increased, if of a stratified stone, by cutting the stone so that the layers will be on edge, like a number of planks, placed side by side. The ancient Greeks and Romans often cut their lintels in this way, and apparently for this reason.

In placing windows in a brick or stone wall the designer should be careful to arrange them so that they will not come under a pier. This is not apt to happen in the front of a building, but it sometimes happens on a side or rear wall, where the windows are placed to suit the interior arrangement and without regard to the external effect.

If a door or window must be placed under a pier or high wall steel beams should be used to support the wall above and also the lintel. Many broken lintels are evidence of a too frequent neglect of this precaution.

Another point that should be carefully considered in laying out the stonework is building the ends of caps and sills into piers. If the

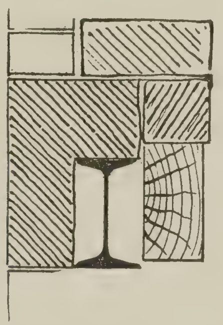

Fig. 96.

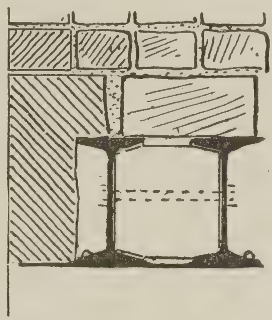

Fig. 97.—⅜-inch Steel Plate Riveted to Beams.

pier extends through several stories the joints will all be slightly compressed and the masonry will settle some, and if the ends of the caps and sills of the adjoining windows are solidly built into the piers they are very apt to be broken as the pier settles.

The best arrangement is to keep the caps and sills back from the face of the pier, and either build pilasters against the pier to receive the caps and sills, as shown at *A*, Fig. 98, or else build the ends of the stones into the pier in such a way that they can give a little. When the cap is back from the face of the pier this can easily be done.

Lintels should have a bearing at each end of from 4 to 6 inches, according to the width of the opening. It is better not to build the ends into the wall more than is necessary to give a sufficient bearing.

Composite Lintels.—Very often it is desired to place a stone lintel over a store window 10 or 12 feet wide. To procure such a lintel in one piece is, in many places, impracticable, and it is therefore

necessary to build the lintel up in pieces. When such is the case at least three stones should be used, and the end joints should be cut as shown in Fig. 99. Cutting the stones in this way binds them together better, and also gives the appearance of being self-supporting. A greater number of stones, say five or seven, may be used if preferred, but the joints should be cut in the same way. Such lin-

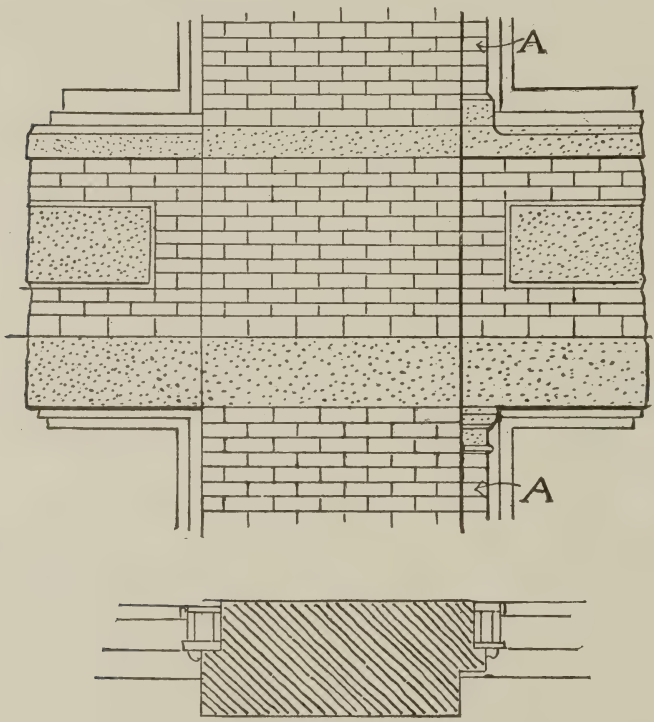

Fig. 98.

tels should always be supported by steel beams, either as shown in Fig. 96 or Fig. 97.

191. Sills.—A "sill" is the piece of stone which forms the bottom of a window opening in a stone or brick wall. Doorsteps or thresholds are also often called "sills."

A *slip sill* is a sill that is just the width of the opening, and is not built into the wall.

Lug sills are those which have *flat* ends, built into the wall, as shown in Fig. 100.

All sills should be cut with a wash of at least $\frac{1}{2}$ inch to 5 inches in depth, and if the ends are to be built into the wall they should be cut as shown in Fig. 100. In some parts of the country the sills are cut with a straight beveled surface the full length of the stone, and where they are built into the wall the bricks are cut to fit the stone. This is not a good method, as the water running down the jamb and

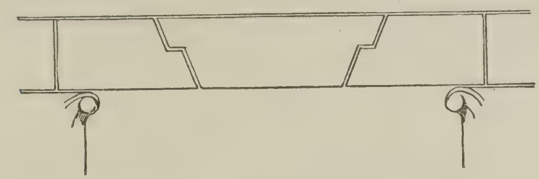

Fig. 99.

striking the sill is apt to enter the joint between the brick and stone, and the slanting surface also offers an insecure bearing for the brick.

Slip sills are cheaper than lug sills, but they do not look as well, and there is also danger of the mortar in the end joint being in time washed out.

Slip sills, however, are not likely to be broken by any settlement in the brickwork, and for this reason many architects prefer to use them for the lower openings in heavy buildings and also for very wide openings.

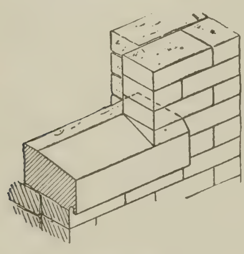

Fig. 100.

Lug sills should not be built into the jambs more than 4 inches, and should only be bedded at the ends when setting.

192. Arches.—Stone arches are very frequently used both in stone and brick buildings. They may be built in a great variety of styles, and with either circular, elliptical or pointed soffits. The method of calculating the stability of a stone arch is the same as for a brick arch, but a stone arch being constructed in larger pieces, the mortar in the joints adds but very little, if any, to the stability of the arch, and a stone arch of the same size as a brick arch is rather more liable to settle or crack than the brick arch, and should be constructed with greater care. The method of calculating the stability of arches is given in Chapter VIII. of the *Architects' and Builders' Pocket Book.* In block stone arches each block, or "voussoir," should always be cut wedge-shape and exactly fitted to the place it is to occupy in the

arch. The joints between the voussoirs should be of equal width the entire depth and thickness of the arch, that the bearing may be uniform over the entire surface. The thickness of the joint will depend somewhat upon the character of the stonework. In finely dressed work $\frac{3}{16}$ of an inch is the usual thickness, while in rock-face work it is seldom made less than $\frac{3}{8}$ of an inch. One-fourth of an inch, however, is all that should be allowed in first-class work.

The joints should also radiate from the centre from which the intrados is struck, or, in the case of an elliptical arch, they should be at right angles to a tangent drawn to the intrados at that point. See Fig. 106, Section 198.

The back of the arch may either be concentric with the intrados, or the ring may be deeper in the centre than at the sides.

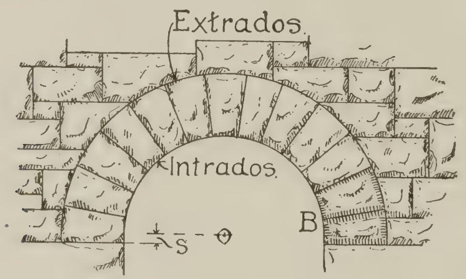

Fig. 101.

The most common stone arch is that shown in Fig. 101, the arch ring being of equal depth and the voussoirs all of the same size, and rock-face, with pitched joints. Occasionally the voussoirs are cut with a narrow margin draft, as shown at *B*. When the springing line of an arch is below the centre, as shown in Fig. 101, the arch is said to be "stilted," the distance *S* being called the "stilt." Stilted arches are very common in Romanesque architecture.

A semicircular arch is one of the best shapes for supporting a wall. It must, however, have sufficient abutment, and the depth of the arch ring, or the distance from the intrados to the extrados, in feet, should be at least equal to $0.2 + \dfrac{\sqrt{\text{radius} + \text{half span}}}{4}$

Arches used in connection with coursed ashlar, especially in Renaissance buildings, often have the voussoirs cut to the shapes shown in Figs. 102 and 103.

Such arches are of course more expensive than arches with the intrados and extrados concentric, as there is more waste to the stone and more patterns are required. They have a more pleasing appearance, however, and are also stronger. Voussoirs of the shape shown in Fig. 103 must be cut with extreme accuracy.

In dividing the arch into voussoirs it should be remembered that, as a rule, narrow voussoirs are more economical of material, but more expensive in point of labor.

In most arches the width of the voussoirs at the bottom is about three-eighths of the width of the ring, although they may vary from one-fourth to one-half.

Very often two voussoirs are cut from one stone, with a false joint cut in the centre. This is done generally for economy, although in

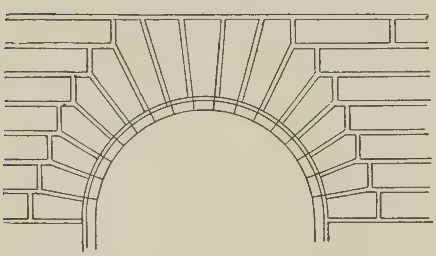

Fig. 102.

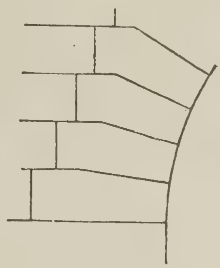

Fig. 103.

some cases it may add to the stability of the arch. Generally the arch is divided into an uneven number of voussoirs, so as to give a keystone, the voussoirs being laid from each side and the keystone fitted exactly after the other stones are set. Except that it is more convenient for the masons there appears to be no necessity of having a keystone, and the author has been informed that Sir Gilbert Scott always used an even number of voussoirs, believing that thereby the danger of the voussoirs cracking was decreased.

193. Label Mouldings.—In nearly all styles of architecture the better class of buildings have the arch ring moulded. In Gothic and Romanesque work a projecting moulding called a "label mould" is generally placed at the back of the arch. When not very large it may be cut on the voussoirs, but usually it is made a separate course of stone, as shown in Fig. 104. When this is the case the depth of the arch ring without the label mould should be sufficient for stability.

The label mould may be cut in pieces of the same length as the voussoirs, or the joints may be made independent of those in the arch.

194. Built-up Arches.—Large arches, especially those which show on both sides of the wall, are often, for the sake of economy, built of several courses of stone, jointed so as to give the appearance of solid voussoirs. Fig. 104 shows the manner in which many of the large arches designed by the late H. H. Richardson were constructed. Every alternate pair of voussoirs should be tied together by galvanized iron clamps.

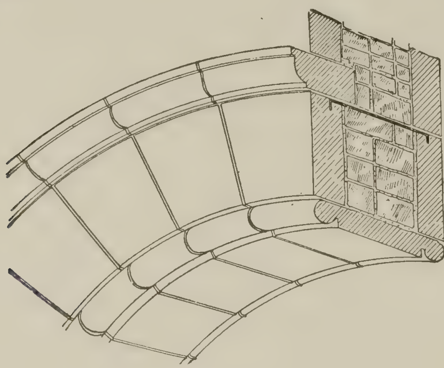

Fig. 104.

195. Backing of Stone Arches.—The arches generally seen in the fronts of buildings are usually only about 6 inches thick, and are backed with brick arches. The brick arch should be of the same shape as the stone arch, and the bricks should be laid in cement mortar, so that there may be no settlement in the joints. The backing should be well tied to the stonework by galvanized iron clamps.

196. Relieving Beams Over Arches.—Very often arches are used for effect in places where sufficient abutments cannot be provided to resist the thrust of the arch. In such cases one or more steel beams should be placed in the wall just above the arch, with the ends resting over the vertical supports and an empty joint left beneath the centre of the beams. The wall above can then be built on these beams, leaving the arches with only their own weight to support. The additional weight which the beams carry to the abutments also greatly increases their resistance to a horizontal thrust. The beams should also be provided with anchors at their ends, with long vertical rods passing through them, to tie the wall together.

Wherever segmental arches are used it is always a safe precaution to place steel rods back of them to take up the thrust of the arch while the mortar in the abutments is green.

197. Support for Spandrels.—Wherever arches are used in groups care must be exercised in laying out the springing stones to give a level support for the spandrels. Thus where two arches come together, as at *A*, Fig. 105, if the first voussoir is cut to the shape of the arch on the back a small wedge-shaped piece of stone would be required to fill the space between the first pair of voussoirs. The weight of the wall above coming on this wedge might be sufficient to force the voussoirs in and seriously mar the appearance of the arch, as well as causing cracks in the ashlar above. This danger may be

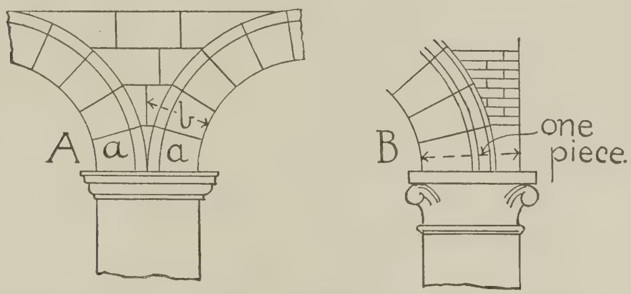

Fig. 105.

overcome by cutting the lower stone, *a a*, in one piece for both arches and extending the voussoir, *b*, to a vertical joint over the centre of the pier. This gives a level bearing for the lower stone in the spandrel and effectually prevents any pushing in of the voussoirs.

Another case very similar to this often occurs where the back of an arch comes almost to the corner of the wall or projection, as shown at *B*. If the distance between the back of the arch and the angle of the wall is less than 8 inches the lower voussoir should be cut the full width of the pier, as shown in the illustration.

198. Elliptical Arches.—Arches built either in the form of an ellipse or oval, or pointed at the centre and elliptical at the springing, are often used for architectural effect in buildings, although very seldom in engineering works. Such arches are very liable to either open at the centre and "kick up" at the haunches, or to fail by the centre voussoirs being forced down. An elliptical arch, especially if very flat, is undesirable for spans of over 8 feet, and should never

be used without ample abutments unless beams are placed above the arch as described in Section 196.

The joints of an elliptical arch should be exactly normal (at right angles) to the curve of the soffit. If the line of the soffit is not a true ellipse, but is made up of circular arcs of different radii, the joints in each portion of the arch should radiate from the corresponding centre. Fig. 106 shows an easy method for laying out the joints where the curve of the soffit is a true ellipse. Let M_1, M_2, M_3, etc., be points on the ellipse from which it is desired to draw the joints. Draw tangents to the ellipse at the points A and B intersecting at C. Draw the lines AB and OC. Draw lines from M_1, M_2, M_3, etc., perpendicular to OA and intersecting OC at L_1, L_2, L_3, etc. From these points draw lines perpendicular to AB, intersecting OA at N_1, N_2, N_3, etc. Lines drawn through N_1M_1, N_2M_2, etc., will then be normal to the curve and give the joints desired.

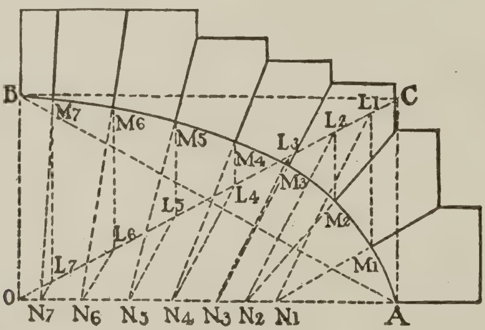

Fig. 106.

199. Flat Arches.—Shallow flat arches of stone, although sometimes pleasing to the eye, are very objectionable constructionally. If a flat arch must be used, to be self-supporting it should be of such height that a segmental arch of proper size can be drawn on its face, as indicated by the dotted lines in Fig. 107. Even then it is desirable to drop the keystone about 1 inch below the soffit line, so as to wedge the voussoirs tightly together. An arch such as is shown in Fig. 107 might be safely used for a span of 5 feet, but with great caution for larger spans. The strength of such an arch may be increased by "joggled" joints, that is, notching one stone into the other, as shown by the dotted lines at *a*. Such joints, however, are quite expensive.

Very shallow flat arches, such as is shown in Fig. 107, should be cut out of one piece of stone, so as to be in reality a lintel with false joints cut on its face. The ends of the lintel should have a bearing on the wall of 6 inches, as shown by the dotted lines, the face being cut away for about 2 inches in depth and veneered with brick. If this method is too expensive the lintel might be cut in three pieces and supported by a heavy angle bar, as shown in Fig. 95.

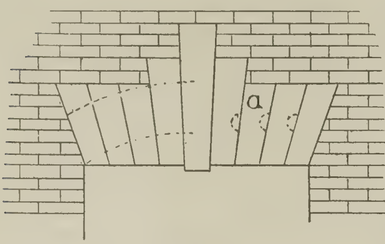

Fig. 107.

Very long lintels are often made in the form of a flat arch (see Section 190), but are, or should be, always supported by steel beams or bars.

Rubble Arches.—Arches are sometimes built of rubble stones. The stones should be long and narrow and roughly dressed to a wedge shape. They should be built in cement mortar, as they depend largely upon the strength of the mortar for their stability.

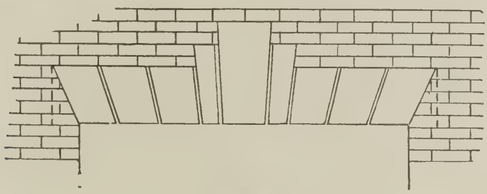

Fig. 108.

200. Centres.—All arches, whether of stone or brick, should be built on wooden centres made to exactly fit the curve of the arch and carefully set. The centres should have ample strength to support the weight of the arch and much of the wall above, as it is undesirable to put any weight on the arch until the mortar in the joints has become hard. Centres are usually made with two ribs cut out of plank and securely spiked together, and the bearing surface formed of cross pieces about 1x2 inches in size nailed to the top of the ribs, as shown in Fig. 109. The ribs forming the supports for the cross pieces should be placed under each edge of the arch, and if the depth of the arch exceeds 12 inches three ribs should be used. The centre should be supported on wooden posts resting on blocks set on the sill or some sufficient support below. It should not be removed until the mortar in the arch joints has had ample time to set.

Centres for spans of considerable extent are framed together with heavier timbers and in a variety of ways. The general method is shown by Fig. 110, which represents a centre for a 10-foot span. The framework, indicated by the straight pieces, is made of 6x6 or 4x8 timbers, and to these are spiked pieces of plank cut to the outline of the arch. The cross pieces are then nailed to the top edge of the planks, as in Fig. 109. Such a centre should have a support under the middle as well as at the sides. As the centres are only

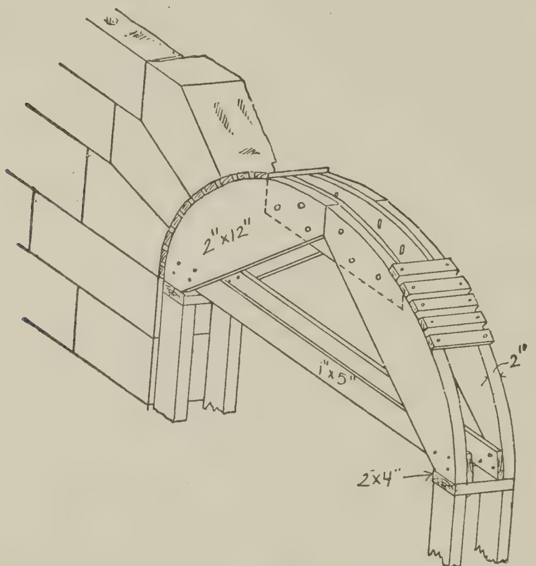

Fig. 109.

required for temporary use, architects generally allow the carpenter to construct them as he deems best, but the superintendent should satisfy himself that they are of ample strength and well supported before the masons commence building the arch.

MISCELLANEOUS TRIMMINGS.

201. *Columns* not exceeding 8 feet in height usually have the shaft cut in one piece and the caps and bases in separate pieces. For columns of greater height it is generally necessary to build the shaft of several pieces. The joints between the cap and base and the shaft, and between the different stones of the shaft, should be dressed perfectly true to the axis of the column and to a true plane, so that

the pressure will be evenly distributed over the whole area of the joint. Nothing but cement mortar should be used in these joints, and the outer edge of the joint for $\frac{3}{4}$ of an inch from the face should be left empty to prevent the outer edges chipping off.

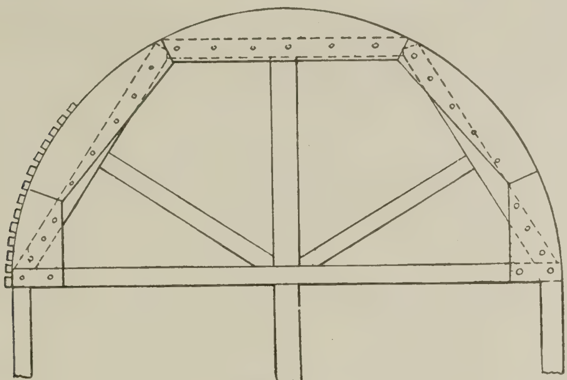

Fig. 110.

If the column is built against a wall, the pieces from which the cap and base are cut should either extend into the wall or be secured by galvanized iron clamps.

Entablatures spanning porch openings, etc., may either be cut from one piece of stone, or, if of considerable height, of several pieces.

Fig. 111.

Fig. 111 shows a common method of building up an entablature, the corona and facia being in still another course above those shown. When jointed as in the figure the bottom joint should not be filled with mortar except at the ends.

The various stones composing the cornice and entablature should be well tied together with iron clamps, and especially at all external corners. It is also a good idea to tie the cornices of porches to the building by long rods built inside the mason work to prevent the porch from "pulling away" from the wall.

202. Copings.—All walls not covered by the roof should be capped by a wide stone called the coping. Horizontal copings should be weathered on top and have a drip at the bottom edge, as shown at *C*, Fig. 112. The width of the coping should be about 3 inches greater than that of the wall.

Gable copings do not require a weathering on top, but they should project about $1\frac{1}{2}$ inches from the face of the wall, and should have a sharp outer edge, so that the water will not run in against the wall. As the weight of the coping has a tendency to cause it to slide on the wall, it should be well anchored to the wall, either by bonding some of the stones into the wall, or by long iron anchors. The bottom stone, sometimes called the "kneeler," should always be bonded well into the wall with a horizontal bed joint, as shown at *K*, Fig. 112. About once in every 6 feet in height a short piece of coping should be cut so as to bond into the wall as at *L*. Gable copings sometimes have the part which rests on the wall cut in steps, so that each stone has a horizontal bearing. This method, however, is very

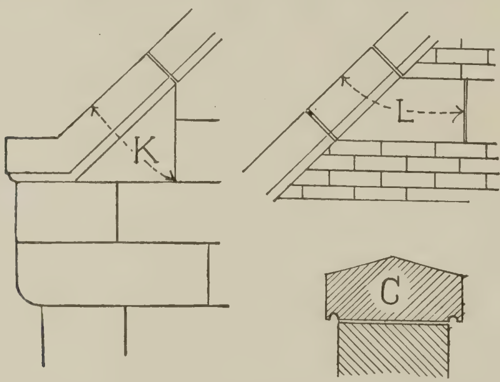

Fig. 112.

expensive, unless the coping is cut in very short pieces, and this is objectionable on account of the number of joints required.

As a rule copings should be in as long stones as possible to avoid joints which admit the wet. Horizontal coping stones are often clamped together at their ends to prevent their getting out of place sideways.

203. Stone Steps and Stairs.—These should always be built of some hard stone, preferably granite, and should have a solid bearing. Outside steps generally rest on a wall at each end, and if more than 6 feet long should have a support at the centre. Each step should rest on the back of the one below at least $1\frac{1}{2}$ inches. Steps to outside entrances should pitch outward about $\frac{1}{8}$ inch. Steps are much more comfortable when cut with a nosing, but owing to the increased expense this is only done in costly buildings.

Stone stairs may be built with only one end supported. In European buildings, and many of our Government buildings, the stairs are constructed as shown in Fig. 113, either with or without nosings. One end of the steps is solidly built into the wall, and each step is supported by the one below, owing to the way in which they are cut. The bearing of one step on the other should not be less than that shown in the figure. The bottom step must obviously be well supported its full length, as it has to sustain nearly the full weight of the stairs. The steps are usually cut with a triangular cross section as shown, as it is less expensive and reduces the weight of the stairs, besides giving a pleasing appearance from below.

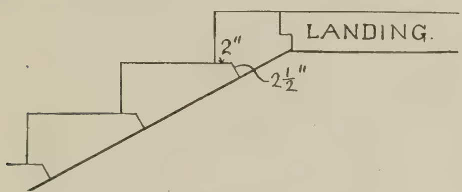

Fig. 113.

The railing is generally of iron, doweled into the ends of the steps.

The laying out and detailing of other stone trimmings will be governed by the principles above noted.

204. Ashlar.—*Laying Out.*—After the kind and size of ashlar to be used has been determined upon the draughtsman should show each piece of ashlar on the elevation drawings if coursed ashlar with plumb bond is to be used, and stones of particular lengths desired. If there are piers on the outside of the building a section drawing should be made showing how the stone in the pier is to be bonded with the rest of the wall.

For all public buildings and most office and business blocks it is generally best to show *every* stone on the plans unless broken ashlar is to be used, when the labor would be wasted. As a rule, in ordinary stone dwellings and in fact most stone buildings, either broken ashlar is used or coursed ashlar of irregular lengths, in which case it is not necessary to indicate the ashlar on the elevation drawings, except to show the height of the courses, if coursed ashlar is used. When broken ashlar is used only the quoins and jambs need be shown, and a small piece of ashlar indicating the kind of work desired, as it would be almost impossible for the masons to carefully follow a drawing of broken ashlar.

Thickness of Ashlar.—Broken ashlar, and coursed ashlar not exceeding 12 inches in height, generally varies from 4 to 8 inches in thickness, and averages 6 inches. The different courses should vary in thickness, as shown in Fig. 117, it being better to have one course

4 inches thick and the next 8 inches than to have all 6 inches. No ashlar, however, should be less than 4 inches in thickness, even if of marble. Ashlar laid in alternating high and low courses, as 6 inches and 14 or 20 inches, should be cut so that the low courses will be at least 8 inches thick and the high courses 4 inches thick, and each stone in the latter courses, when 18 inches or more in height, should have at least one iron anchor extending through the wall.

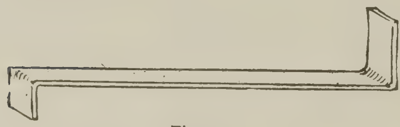

Fig. 114.

Fig. 114 shows the form of anchor generally used. The high courses, when of sandstone or limestone, are generally sawed of a uniform thickness.

Joints.—It is important that the surface of each stone shall be "out of wind," that is, a true plane, and square to the bed and end joints.

The bed joints should be full and square to the face and not worked hollow, as in Fig. 115, as with hollow joints the least settlement in the mortar will throw the whole pressure on to the edge of the stone at *C*, and cause a "spall" or pieces to splinter off, which ruins the appearance of the building, and, moreover, causes a suspicion as to its safety. Stonecutters are very apt to work the joints hollow and the back of the joint slack, as in Fig. 116, as it requires

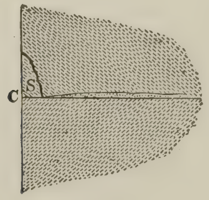

Fig. 115.

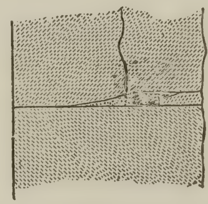

Fig. 116.

much less labor than to dress the joint evenly, and, unless carefully looked after, will cut the stone that way in nearly nine cases out of ten. If the back of the joint is left slack and underpinned, as in Fig. 116, the stone is then supported only at the front and back, and liable to break in the middle, as shown. Of course, in a wall not exceeding 20 feet in height, the danger arising from imperfect joints is not as great as in a wall of six or more stories. The higher the wall the more carefully should the joints be cut. It is also desirable that the joints should not be convex.

For very heavy masonry, as in the basement or first story of tall buildings, it is desirable to use rusticated joints (see Fig. 90), as with such joints there is less chance for the face to spall.

The thickness of ashlar joints varies from $\frac{3}{16}$ to $\frac{1}{2}$ inch. A $\frac{1}{4}$-inch joint, when pointed, makes very good-looking work. A $\frac{1}{2}$-inch joint is too wide for anything but rock-face ashlar, and nothing over a $\frac{1}{4}$-inch joint should be used for heavy work.

205. *Backing.*—Both stone and brick are used for the backing of ashlar. Brick is more largely used for this purpose than stone, because in most cases it is the cheapest, and it possesses the further advantage that the plaster may in dry climates be applied directly to the brick, while the stone backing generally has to be plugged and stripped for lathing. If brick is used for backing the joints should be made as thin as possible, and it is desirable to use some cement in the mortar to prevent shrinkage in the joints. The backing, if of brick, should never be less than 8 inches in thickness. If a hard laminated stone, with perfectly flat and parallel beds, can be obtained for backing, it makes a stronger job than brick, but irregular rubble blocks are not suitable for anything but dwelling house walls, unless the walls are made one-fourth thicker than with brick backing. The backing, whether of brick or stone, should be carried up at the same time with the ashlar, and, if of stone, should be built in courses of the same thickness as the ashlar, as shown in *B*, Fig. 117.

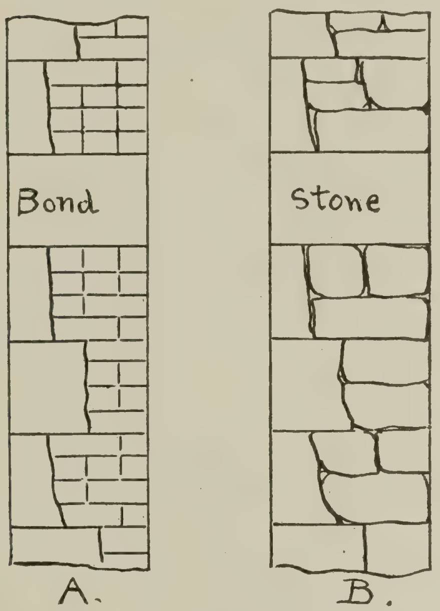

Fig. 117.

Bonding.—Ashlar not exceeding 12 inches in height is usually bonded sufficiently to the backing by making the stones of different thicknesses, as in Fig. 117, and by having one through stone to every 10 square feet of wall.

Where the ashlar is only about 2 inches or 4 inches thick, as is generally the case with marble, and often with sandstones, each piece of ashlar should be tied to the backing by an iron clamp, about $\frac{1}{8}$ of an inch thick and 1 or $1\frac{1}{4}$ inches wide, with the ends turned at right angles, as shown in Fig. 114. The anchors should be made of just the right length for the longer end to turn up just on the inside of the wall. Every stone should have one clamp, and if over 3 feet long two clamps should be used. There should also be belt courses about every 6 feet, extending 8 inches or more into the wall, to give support to the ashlar.

The effective thickness of a wall faced with thin ashlar is only equal to the thickness of the backing. When iron clamps are used for tying the ashlar they should be either galvanized or dipped into hot tar to prevent being destroyed by rust.

206. Slip Joints.—Where two walls differing considerably in height come together, as for instance where the front or side wall of a church joins the tower, the two walls should not be bonded together, but the low wall should be "housed" into the other, so as to form a continuous vertical joint from bottom to top, as shown in Fig. 118.

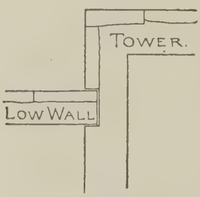

Fig. 118.

Such a joint is called a slip joint. All mason work built with lime mortar will settle somewhat, owing to a slight compression in the joints, and this settlement is sometimes sufficient to cause a crack where a high and low wall are bonded together. In such cases there is also a chance for uneven settlement in the foundations, even when carefully proportioned. With a slip joint a moderate settlement may take place without showing on the outside.

207. Bond Stones and Templates.—The building regulations of certain cities require that bond stones shall be used in brick piers of less than a certain size. When such stones are used they should be of some strong variety, and should be cut the full size of the pier. It is also very important that the outside and inside bricks be brought exactly to the same level to receive the stone, for if the stone bears only on the outside bricks the weight will cause them to buckle and separate from the pier, while if the weight is borne by the centre of the pier it is liable to crack through the middle.

Bond stones should not be used in a wall in the manner shown in Fig. 119, as they give the pressure no chance to spread, but keep con-

centrating it back on the part of the wall immediately under the bond stones, as shown by the short vertical lines.

Bearing stones used under the ends of beams or girders to distribute the weight on the walls are called *templates*. They should always be of a very hard, strong stone, laminated if it can be obtained, and the thickness of the stone should be one-third of the narrowest dimension of the stone, unless the stone is unnecessarily large, but in no case less than 4 inches. It is always better that templates be too large rather than too small.

The area of the templates should be such that the pressure which it transmits to the wall below shall not exceed 120 pounds per square inch for common brickwork, or 150 pounds for common rubble with flat beds.

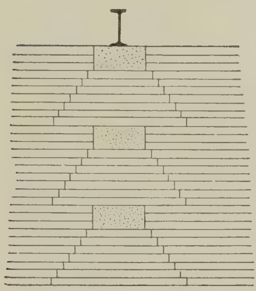

Fig. 119.

It is also a good idea to place a flat stone *above* the end of a wooden girder, so that the wall will not rest on the wood, which is quite sure to shrink and possibly affect the wall.

208. Setting Stonework.—All stones should be set in a full bed of mortar, and any stone too large to be easily lifted by one man should be set with a derrick.

In some localities slips of wood are prepared of the thickness desired for the joints and laid on the top of the stone below, so that when the stone is set the mortar squeezes out until the stone rests on the slips of wood. After the mortar has set or hardened the slips are withdrawn. The bed of mortar should always be kept back an inch or more from the edge of the stone. This will prevent the stone bearing just on the outer edge, and save raking out the mortar preparatory to pointing. In damp places stonework should be set in cement, or lime and cement mortar; in dry situations it may be set in lime mortar.

Most of the granular limestones and marbles, and some sandstones, are stained by either Portland or Rosendale cement, and when using any of these stones for the first time the architect should ascertain their liability to stain. The mortar for bedding the stone can always be kept from the face of the stone by exercising a little care, and the joints afterward pointed with some material that does not stain. Stone masons are often very careless in setting stonework, and do not bed the stones evenly, so that when the weight comes upon them they crack.

Marble and limestone are sometimes set in a cement made of lime, plaster of Paris and marble dust, and called Lafarge cement. When such cement is used for setting, and other cements for the backing, the back of the stone ashlar should be plastered with the former cement. Window and door sills should only be *bedded at their ends* when set and no mortar put under the middle of the sill, otherwise the settlement of the walls will break the sill.

Protecting.—The carpenter's specifications should contain a clause providing for the boxing of all mouldings, sills and ornamental work with rough pine to prevent the stone being damaged during the construction of the building. It is said that hemlock stains the stone, and should therefore never be used for this purpose.

209. Pointing.—As the mortar in the exposed edges of the joints is especially subject to dislodgment through the expansion and contraction of the masonry and the effects of the weather, it is customary after the masonry is laid to refill the joints to the depth of half an inch or more with mortar prepared especially for this purpose. This operation is called pointing.

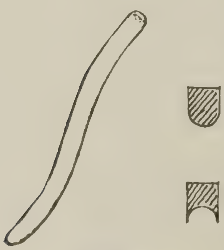

Fig. 120.

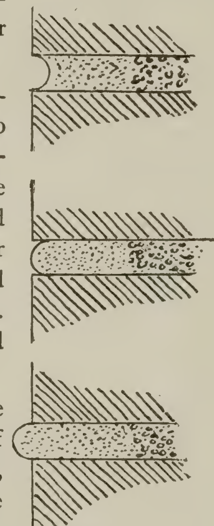

Fig. 121.

Pointing is generally done as soon as the outside of the building is completed, unless it should be too late in the season, when it should be delayed until spring. Pointing should never under any circumstances be done in freezing weather. It is also not desirable to do it in extremely hot weather, as the mortar dries too quickly.

Portland cement mixed with not more than an equal volume of fine sand and such coloring matter as may be required, with just enough water to give the compound a mealy consistency, makes the most durable mortar for pointing. If the stone is stained by cement, Lafarge cement should be used, or a putty made of lime, plaster of Paris and white lead.

Before applying the pointing the joint should be raked out to the depth of an inch, brushed clean and well moistened.

The mortar is applied with a small trowel made for the purpose and then squeezed in and rubbed smooth with a tool called a jointer (Fig. 120) and made for that purpose. Jointers are made with both hollow and concave edges, so as to give a raised or concave joint, as shown in Fig. 121. The concave joint is the most durable, although the raised joint makes perhaps the handsomest work.

Cleaning Down.—This consists in washing and scrubbing the stonework with muriatic acid and water. Wire brushes are generally used for marble work and sometimes for sandstone, but stiff bristle brushes usually answer the purpose as well. The stones should be scrubbed until all mortar stains and dirt are entirely removed. The cleaning down is done in connection with the pointing.

For cleaning an old front the sand blast, using either steam or compressed air, does the work most effectively, as it removes from $\frac{1}{64}$ to $\frac{1}{32}$ of an inch from the surface of the stone, making it look like new. Even carving can be successively treated in this way.

210. Strength of Stone Masonry.—Practically the only cases in which the strength of stonework need be considered by the architect, other than to see that proper construction is provided, are: *a*, the strength of piers; *b*, strength of columns; *c*, strength of lintels.

Strength of Stone Piers.—The following figures may be taken for the working strength of stone piers. The figures in the first column may be taken for a fair quality of work laid in good lime mortar, those in the second column for the best class of work laid in cement:

Concrete	5 to 20	tons.
Rubble	5 to 15	"
Squared stone, ½-inch joints	15 to 20	"
Sandstone ashlar, ¼-inch joints	10 to 20	"
Limestone ashlar, ¼-inch joints	20 to 25	"
Granite ashlar, ¼-inch joints	30	"

The ashlar to be at least as thick as it is high and well bonded.

Strength of Columns.—A stone column, free from defects, carefully bedded and not exceeding ten diameters in height, should *safely* carry a load equal to one-fifteenth of the breaking load of stone of the same kind and quality. Any column loaded with over fifteen tons to the square foot should be bedded in Portland cement mortar, of not more than 1 to 1, and the mortar should not be allowed to come within 1 inch of the edge of the column until after the building is done, when the joint may be pointed the same as ashlar. As it is difficult to secure a joint which will stand more than forty tons to the square foot, that should be the limit of load for a stone column,

no matter how strong the stone is, unless extra precautions are taken with the joints. The following values may be used for the safe loads of columns of the different stones specified, the shaft of the column being in one piece :

Longmeadow (Mass.) red sandstone, best....	35	tons per	square foot.
Potsdam red sandstone....................	40	"	"
Manitou (Colo.) red sandstone, best....	25 to 30	"	"
Ohio sandstone..........................	25	"	"
Fond du Lac (Wis.) sandstone............	25	"	"
Limestone, Glens Falls, N. Y.............	35	"	"
Limestone, Indiana.................	25 to 35	"	"
Limestone, strongest varieties.............	40	"	"
Marble, Lee, Mass......................	40	"	"
Marble, Rutland, Vt................	30 to 35	"	"
Granite, any, of good quality..............	40	"	"

If the columns are built up of several pieces the joints should not exceed $\frac{3}{16}$ of an inch in thickness, and the bed surfaces should be perfectly true and square to the axis of the column.

211. *Strength of Lintels.*—A lintel is nothing more than a stone beam, and the same formulæ apply to stone as to wood, with the exception of the quantity representing the strength or "modulus of rupture" of the material. The following formulæ give the strength of lintels under distributed and concentrated loads, the only cases likely to occur in practice :

$$\text{Distributed breaking load} = \frac{2 \times \text{breadth} \times \text{square of depth}}{\text{span in feet}} \times C.$$

Concentrated centre breaking load = one-half the distributed load.

The breadth and depth should be taken in inches. C is one-eighteenth of the average modulus of rupture, and may be taken as follows :

Granite, 100 ; marble, 120 ; limestone, 83 ; sandstone, 70 ; slate, 300 ; bluestone flagging, 150.

These formulæ give the *breaking strength* of the lintel. If the load on the lintel consists only of masonry, and is not subject to shocks or impact of any kind, the safe load may be taken at *one-sixth* of the breaking load. If there are any unfavorable circumstances the safe load should not exceed *one-tenth* of the breaking load.

Nearly all laminated stones are stronger, as beams, when set on edge, and where the full strength of the stone is required, they may with advantage be set in this way and be protected from the weather by placing a moulded course above set on its natural bed.

Floor beams, or any construction carrying a live or moving load, should never be supported on a stone lintel. The above formulæ apply to a slab as well as to a lintel, although if the slab has a bearing on all four sides the strength will be considerably increased.

Example.—What is the safe distributed load of a granite lintel, 6 feet opening, 20 inches high and 8 inches thick?

Answer.—Breaking strength $= \frac{2 \times 8 \times 20^2}{6} \times 100 = 106,666$ pounds.

One-sixth of this gives 17,777 pounds for the safe distributed load.

Example II.—What is the safe distributed load for a bluestone flag 4 feet clear span, 4 feet wide and 4 inches thick?

Answer.—Breaking load $= \frac{2 \times 48 \times 4^2 \times 150}{4} = 57,600$ pounds.

As the load on a flag would very probably be a live or moving load, we will make the safe load only one-tenth of the breaking load, or 5,760 pounds.

212. Measurement of Stonework.—Rough stone from the quarry is usually sold under two classifications, *rubble* and *dimension* stone. Rubble includes the pieces of irregular size most easily obtained from the quarry, and suitable for cutting into ashlar 12 inches or less in height and about 2 feet long. Stone ordered of a certain size, or to square over 24 inches each way, and of a particular thickness, is called dimension stone. The price of the latter varies from two to four times the price of rubble.

Rubble is generally sold by the perch or car load. Footings and flagging are usually sold by the square foot; dimension stone by the cubic foot. In Boston granite blocks for foundations are usually sold by the ton, and rubble for foundations is often sold that way in various localities.

In estimating on the cost of stonework *put into the building*, the custom varies with different localities, and even among contractors in the same city.

Dimension stone footings (that is square stone 2 feet or more in width) are usually measured by the square foot. If built of large rubble or irregular stones the footings are measured in with the wall, allowance being made for the projections of the footings.

Rubble work is most often measured by the perch, which consists of $24\frac{3}{4}$ cubic feet in the East and of $16\frac{2}{3}$ cubic feet (by custom) in Colorado, and in some localities 22 cubic feet are called a perch.

If work is let by the perch it should be distinctly stated in the contract the number of cubic feet that are to constitute a perch, as the

custom of the place would probably prevail in a dispute. It should also be stated whether or not openings are to be deducted ; as a rule rubble walls are figured solid, unless the opening exceeds 70 square feet.

Occasionally rubble is measured by the cubic yard, or 27 cubic feet, and by the cord of 128 cubic feet.

Stone backing is generally figured the same as rubble.

Ashlar is almost invariably measured by the square foot, the price varying with the kind of work and size of stones. Openings are generally deducted, but width of jambs measured in with the face work. This custom varies, however, with different localities and kind of work. In common rock-face ashlar the wall is often figured solid unless the openings are of unusual size.

Flagging and slabs of all kinds are always figured by the square foot.

Mouldings, belt courses and cornices are usually figured by the lineal foot, irregular shaped pieces by the cubic foot. All carving is figured by the piece. Some contractors figure all kinds of trimmings by the cubic foot, varying the price according to the amount of labor involved. Others figure the cubic feet in all the stone to get the value of the rough stone, and then figure the labor separately—so much per lineal foot for mouldings, so much for columns, and a separate figure for carving. This is the most accurate method, and is usually employed by contractors for granite work. Of course considerable experience is necessary to know how much to allow for labor ; the value of the stone itself can be very easily computed.

213. Superintendence of Cut Stonework.—As with all other building operations, the superintendent needs to be very watchful in inspecting the cut stonework and its setting, to prevent defects and imperfect work being imposed upon him. When a stone is once built into a wall it can only be removed at considerable expense and delay and much vexation, and it is therefore important that all defects be discovered before the stone is set. The superintendent must also be well posted on the various ways in which defects are covered up, so that he may discover them, if any exist, and have sufficient firmness to demand that all unsound or defective stones shall be replaced by sound ones, and that the work shall be done in the manner directed by the architect.

Defects.—The following are the defects most likely to occur in cut stonework.

Good granites are liable to contain local defects, such as seams, black or white lumps called "knots," and also brown stains known

as sap. Any of these defects should cause the stone to be rejected. Seams may be detected by striking the stone with a hammer, and those which do not ring clearly should be rejected.

In sandstones the most common defects are "sand holes" (which are small holes filled with sand, but without any cementing material, so that the sand soon washes out) and uneven color. Stones from the same quarry often vary considerably in color, and the superintendent must see that the color of the stone is uniform throughout.

Patching.—Often in cutting stone a small piece will get broken from a large stone, and the contractor, rather than throw the stone away, will either stick the piece on again or cut out the fractured part and fit in a new piece. The pieces are glued on with melted shellac and then rubbed with stone dust until they cannot be noticed by a casual glance, and the superintendent must look sharply at the stones to be sure that they have not been patched in this way.

At first these patches are hardly noticeable and do no harm, but when the stone gets wet the patch becomes conspicuous, and in time the shellac in the joint is washed away and the patch drops off.

When the damaged stone is large, and cannot be replaced except at great expense and considerable delay, the superintendent might consent to have it patched, but he should see that it is done right, and, where possible, a square hole should be cut in the stone and a corresponding piece tightly fitted in, and then cut to fit the stone or moulding. If on the corner of a stone the piece can generally be dovetailed, so that it will stay in place without the aid of shellac. If any patched stones are put into the building the superintendent should know of it beforehand, and, as a rule, it will be wise to consult the owner of the building about it before the stone is set.

In the cutting of the stone the most common fault to be found is poor workmanship or too coarse a surface. Naturally the finer a surface is tooled or crandalled the greater the expense, hence contractors will generally finish the stone as coarse as they think the superintendent will pass. Very often, also, sufficient care is not taken in matching the ends of moulded belt courses, cornices, etc. The superintendent should insist that all the pieces are cut exactly to the same pattern, and that all edges are true and free from nicks.

It is a very common occurrence to find some window sills that are not of sufficient width to be well covered by the wood sill. The back of the stone sills should extend at least $1\frac{1}{2}$ inches beyond the face of the wood sill, and the back of the wash should be cut to a straight line, without any holes or scant surfaces.

The ashlar, especially when rock-face, is apt to be too thin in places, and to have very poor bed joints. The superintendent should insist that the bed joints, top and bottom, be at least 3 inches wide at the thinnest part, and that they be cut square to the face of the work. He should also examine the stones to see that they have been cut so as to lay on their natural beds. The proper bonding and anchoring of the ashlar and trimmings should also receive careful attention. The anchoring of gable copings should be especially looked after, as it is not infrequent that such copings slide out of place and fall to the ground from neglect in this particular. One would naturally suppose that the builder himself would see that his work was done securely, if not handsomely; but it seems to be a general fault amongst builders to trust a good deal to luck, and to use as few precautions to insure it as possible. In these days, when everything is done with a rush, there are also many builders that are ignorant of the best methods of doing work, or that consider them unnecessary and not "practical."

When finials or similar stones are cut in two pieces they should be secured together by iron dowels set in almost clear Portland cement. The superintendent should constantly bear in mind that stonework cannot be too well anchored and bonded.

The superintendent should also caution the foreman, when setting arches, columns, etc., not to let the mortar come within $\frac{3}{4}$ of an inch of the face of the stone. Moulded arches, particularly, need to be set with great care, as if the mortar comes out to the face the joint may be a little full at the edge and cause the moulding to "sliver" or "spall" at the joints. It is not uncommon to see arch stones and columns cracked on account of neglect of this precaution.

When the pointing is being done the superintendent must carefully watch the operation of raking out the joints to receive the pointing. The old mortar should be raked out to the depth of at least $\frac{3}{4}$ of an inch. If the work is not watched, however, it may be found in a year or two that the raking of the joints was only partially done, if not neglected altogether, and that the pointing mortar was only stuck on to the face of the joint.

There will naturally be many other points in connection with the stonework that will require careful supervision to secure a good and durable job, but careful attention to those above noted will lead to a pretty thorough inspection of the whole work.

Chapter VII.

BRICKWORK.

BRICKS.

214. Bricks are more extensively used in the construction of buildings than any other material except wood. At the present time brick and terra cotta architecture is decidedly in the ascendency, and a great deal of capital is invested in the manufacture of bricks of all kinds, shapes and colors.

Good bricks possess the advantage over stone of being practically indestructible, either from the action of the weather, the acids of the atmosphere or fire ; they may be had in almost any desirable shape, size or color, and are more easily handled and built into a wall than stone. Brickwork is also much cheaper than cut stonework, and in most localities is less expensive than common rubble. Unfortunately, however, all bricks cannot be classed under the above heading, as there are many that are soft and porous, and are far from durable when exposed to dampness. Except in very dry soils bricks are not as well adapted for foundations as stonework, nor can they be used for piers and columns that support very heavy loads.

As there are many different kinds and qualities of bricks, as well as good and bad methods of using them, the architect must know something about the manufacture of bricks, their characteristics and the best methods of using them to properly prepare his designs and specifications and to superintend the construction.

215. Composition of Bricks.—Ordinary building bricks are made of a mixture of clay and sand (to which coal and other foreign substances are sometimes added), which is subjected to various processes, differing according to the nature of the material, the method of manufacture and the character of the finished product.

After being properly prepared the clay is formed in moulds to the desired shape, then dried and burnt.

The Clay.—The quality of a brick depends principally upon the kind of clay used. The material generally employed for making common bricks consists of a sandy clay, or silicate of alumina, usually containing small quantities of lime magnesia and iron oxide. If

the clay consists almost entirely of alumina it will be very plastic, but will shrink and crack in drying, warp and become very hard under the influence of heat.

Silica, when added to pure clay in the form of sand, prevents cracking, shrinking and warping, and allows a partial vitrification of the materials. The larger the proportion of sand present the more shapely and uniform in texture will be the bricks. An excess of sand, however, renders the bricks too brittle and destroys cohesion. Twenty-five per cent. of silica is said to be a good proportion.

The presence of *oxide of iron* in the clay renders the silica and alumina fusible and adds greatly to the hardness and strength of the bricks. Iron also has a great influence upon the color of the bricks (see Section 229), the red color being due to the presence of iron. A clay which burns to a red color will make a stronger brick, as a rule, than one whose natural color when burnt is white or yellow.

"*Lime* has a twofold effect upon the clay containing it. It diminishes the contraction of the raw bricks in drying, and it acts as a flux in burning, causing the grains of silica to melt, and thus binding the particles of the bricks together. An excess of lime causes the bricks to melt and lose their shape. Again, whatever lime is present must be in a very divided state. Lumps of limestone are fatal to a clay for brickmaking. When a brick containing a lump of limestone is burnt the carbonic acid is driven off, the lump is formed into 'quicklime' and is liable to slake directly the brick is wetted or exposed to the weather. Pieces of quicklime not larger than pin heads have been known to detach portions of a brick and to split it to pieces. The presence of lime may be detected by treating the clay with a little dilute sulphuric acid. If there is lime present an effervescence will take place."

For the best qualities of pressed brick the clay is carefully selected both for chemical composition and color, and very often two or three qualities of clay from different sources are mixed together to obtain the desired composition.

Clays of especially fine quality are often mixed and shipped to distant portions of the country the same as other raw materials.

216. Manufacture.—*Handmade Bricks.*—Most of the common bricks used in this country, especially in the smaller towns and cities, are still made by hand. The process consists of throwing the clay into a circular pit, where it is mixed with water and tempered with a tempering wheel worked by horse power, until it becomes soft and plastic, and is then taken out and pressed into the moulds by hand.

Unless the clay already contains sufficient sand, additional sand is added to it as it is put into the pit, and often coal dust or sawdust is added to assist the burning. In some localities screened cinders are mixed with the clay.

In moulding brick by hand the mould is dipped either in water or fine sand to prevent the bricks from adhering to the mould. If dipped in water the process is called "slop moulding," and if in sand the bricks are called "sand struck." The latter method gives cleaner and sharper bricks than those produced by "slop moulding."

After being shaped in the mould the bricks are laid in the sun, or in a dry house, to dry for three or four days, after which they are stacked in kilns and fired.

When the green bricks are dried in the open air they occasionally get caught in a shower, which gives them a pitted effect, that is generally considered undesirable. Unless the edges are much rounded, however, it does not affect the strength of the bricks, and they may be used in the interior of the wall.

217. *Machine-made Bricks.*—Where bricks are made on a large scale the work is now done almost entirely by machinery, commencing with the mining of the clay by steam shovels and ending by burning in patent kilns.

A great variety of machines are now made for preparing the clay and for making the raw bricks; they differ more or less widely in construction and principle, but may be divided into three classes, according to the method of manufacture for which they are adapted.

There are practically three methods employed in making bricks, viz.: The *soft mud* process, the *stiff mud* process and the *dry clay* process, and the machines are also classed under one of these headings.

The general processes employed in these methods are as follows:

Soft Mud Process.—This is essentially the same process as that employed when the bricks are made by hand. When machinery is used the various steps are about as follows: As the clay is brought from the bank it is thrown into a pit (about 6 feet deep and 8x12 feet in area) lined with planks; water is then turned into the pit and the clay allowed to soak for twenty-four hours. Generally three pits are provided, so that the clay in one may be soaking while the second is being emptied and the third filled. If coal dust is to be mixed with the clay it is thrown into the pit in the proper proportion. After soaking twenty-four hours in the pit the clay is thrown out on to an endless chain, which carries it along to the machine, into which it

falls. The upper part of a soft clay machine contains a revolving shaft, to which arms are affixed. These arms break up and thoroughly work the soft clay, and it falls to the bottom of the machine, where revolving blades force it forward, and a plunger working up and down forces the clay into a mould placed under the orifice. The filled mould is then drawn or forced out on to a shelf or table and another mould placed under the machine. There are several styles of machines, but they all work on about this plan. Sometimes the clay is worked in a pug mill before being thrown into the machine.

After being drawn from the machine the filled moulds are emptied by hand and the bricks taken to the dry shed. For drying soft mud bricks the "pallet" system is generally employed. The "pallets" are thin boards about 12x24 inches in size. The bricks are placed on these, and then the pallets are placed on racks, arranged so that the air may have free access to the bricks. The stacks should always be protected by a low roof.

218. Stiff Mud Process.—The essential difference between this process and the foregoing is that in the stiff mud process the clay is first ground, or disintegrated, and only enough water is added to make a stiff mud. The mud, after being pugged, is forced through a die in a continuous stream, whose section is the size of a brick, and the bricks are then cut off.

The process varies more or less in different yards and with different clays, but when most thoroughly carried out the various steps in their order are as follows: First, the mining of the clay; second, breaking up the lumps (generally in a pug mill); third, grinding of the clay, usually in a dry pan (see Section 221); fourth, tempering the clay, either in a separate pug mill or in the machine, and fifth, passing the clay through the machine and cutting off the bricks.

There are two primary types of stiff mud brick machines, viz.: The auger and plunger types. Of these the auger machines are the most numerous and generally considered the most satisfactory. The auger machine consists of a closed tube of cylindrical or conical shape, in which, on the line of the axis of the tube, revolves a shaft, to which is attached the auger and auger knives. The knives are so arranged as to cut and pug the clay and force it forward into the auger. The function of the auger is to compress and shape the clay and force it through the die. When the clay passes through the die it is compressed to as great an extent as it can be in its semi-plastic condition. The opening in the die is made the size either of the end

or side of a brick, and a continuous bar of clay is constantly forced through it on to a long table. Various automatic arrangements are provided for cutting up this bar into pieces the size of a brick. If the section of the bar is the same size as the end of a brick the bricks are end cut; if the section of the bar is that of the side of a brick the bricks are side cut. With the end-cut brick the clay may issue from the machine in one, two, three or even four streams.

From the cut-off table the green bricks pass to the off-bearing belt, from which they are taken to the represses or dryers.

In the plunger brick machine the clay is forced into a closed box or pressing chamber, in which a piston or plunger reciprocates and forces the clay through the die. The action of this type of machine must of necessity be intermittent. When the plunger machine is used the clay is generally tempered in a pug mill before passing to the machine.

219. Comparison of Soft Mud and Stiff Mud Bricks.—Soft mud bricks are made under little or no pressure, and are, therefore, not as dense as the stiff mud bricks. It is claimed, however, that in the soft mud bricks the particles adhere more closely, and that when the brick are properly made and burned they are the most durable of all bricks. Soft mud bricks, after having lain in a foundation on the shore of a river for fifty-four years, were found in as perfect condition as when laid. Soft mud bricks are also generally more perfect in shape than stiff mud bricks and better adapted for painting.

Stiff mud bricks, owing to the nature of the clay and the details of manufacture, often contain laminations, or planes of separation, which more or less weaken the bricks.

Those made by the plunger machine also sometimes contain voids caused by the air which occasionally passes with the loose clay into the pressure chamber, and, being unable to escape, passes out with the clay stream and renders it more or less imperfect.

The manufacture of stiff mud bricks, however, is constantly increasing.

In some localities soft mud bricks are the cheapest; in others the stiff mud have the advantage. The difference in cost, however, is usually very slight.

The soft mud bricks take longer to dry, but are more easily burnt.

220. *Repressing.*—Both soft and stiff mud brick are often repressed in a separate machine. Repressing reshapes the brick, rounds the corners if desired, trues it in outline and makes a considerable

improvement in its appearance. A properly formed stiff mud brick, however, is not improved in structure by repressing.

221. Dry Clay Process.—This process is especially adapted to clays that contain only about 7 per cent. of moisture as they come from the bank, the clay being apparently perfectly dry. Wet clays are sometimes dried and then submitted to the same process, but the expense of drying materially increases the cost of manufacture.

The various operations generally employed in making brick by this process may be briefly described as follows :

The first step is the mining of the clay, which may be done either by hand or steam shovel, according as circumstances may direct. After being mined the clay is generally stored under cover, so as always to have a supply on hand, and also to permit of further drying and disintegrating. Sometimes, however, the clay is taken directly from the bank to the dry pan.

Probably most of the dry press brick that are manufactured are made from two or more grades of clay, which are mixed in proportions determined by trial as the clay is thrown into the dry pan.

From the dump the clay is thrown into a dry pan, which is a circular machine about 4 feet in diameter and 2 feet deep, with a perforated metal bottom. In this machine, or pan as it is called, are two wheels, which constantly revolve on a horizontal axis and grind the clay between them and the bottom of the pan, the pan itself revolving at the same time. The clay as it is ground passes through the holes in the bottom of the pan and falls on to a wide belt, which carries it above an inclined screen, on to which it falls. Such portions of the clay as are sufficiently finely ground fall through the screen on to another belt, and the coarser particles roll into the dry pan, to be again ground and carried on to the screen.

The belt which receives the fine clay from the screen carries it to a mixing pan, which is a machine contrived to thoroughly mix the particles of the clay. From the mixing pan the clay falls into the hopper of the pressing machine, and from the hopper it falls into the moulds, where it is subjected to great pressure, which compresses it to the size of the brick and then pushes the pressed brick on to a table. From the table of the machine the bricks are taken by hand, placed on a barrow, or car, and transferred to the kiln.

Different manufacturers may vary these operations somewhat, but the process, and also the machines, are essentially like the above in manufacturing pressed brick.

The pressing machines are so constructed that the loose clay is made to evenly fill a steel box of the width and length of the intended brick, but much deeper. Into these boxes a plunger is forced, which compresses the clay until the desired thickness is reached, when the plunger stops. If the clay falls more compactly into one box, or mould, than into another, the brick from the first mould will be the denser, as the plunger falls just so far, no matter how much clay is in the mould.

Moulded bricks are made in exactly the same way, the only difference being that the box is made to give the shape of brick desired.

Most of the pressed brick machines admit a small jet of steam into the clay just before it passes into the moulds to slightly moisten it.

Bricks made by this process are very dense, and generally show a high resistance to compression, but the general opinion is that the particles do not adhere as well as when the clay is tempered, and that dry pressed bricks will not prove as enduring as soft mud bricks, although the former are now most extensively used for face bricks.

When the term *pressed bricks* is used it should refer to bricks made by the dry process, although many so-called pressed bricks, or face bricks, are made by repressing soft mud bricks.

222. Drying and Burning.—Bricks made by the soft mud process always have to be dried before placing in the kiln ; those made by the stiff mud process are generally, although not always, stacked in a dry house from twelve to twenty-four hours. The drying of the bricks is an important process, and where bricks are manufactured on a large scale the drying is generally accomplished by artificial means.

After being sufficiently dried the bricks are stacked in a *kiln* and burned.

Three styles of kilns are used for burning bricks, viz.: *Up-draft*, *down-draft* and *continuous*.

Up-draft Kiln.—This is the style of kiln that was almost universally used in this country for burning bricks previous to 1870, and is still used more than either of the other kilns, especially in small yards where the bricks are manufactured by hand.

The old-fashioned up-draft kiln is nothing but the bricks themselves built into a pile about 20 to 30 feet wide and 30 to 40 feet long, and perhaps 12 or 15 feet high. The sides and ends of the piles are plastered with mud to keep in the heat, and the top is generally covered with dirt and sometimes protected with a shed roof

The bricks are piled in such a way as to form a row of arched openings extending entirely across the kiln, and in these arches the fire is built. The dried bricks are loosely piled above these arches, and as the kiln is burnt those nearest the fire are so intensely heated as to become vitrified, while those at the top of the kiln are but slightly burned, with a gradual gradation of hardness between them. It is from this difference in the burning that the terms "arch brick," "red brick" and "salmon brick" originated. As there is nothing but the natural tendency of heated air to rise to produce a draft, its direction is of course upward, hence the name.

The modern up-draft kiln has permanent sides made of a 12 or 16-inch brick wall laid in mortar, and heat is generated in ovens with iron grates built outside of the permanent walls, and only flames and heat enter the kiln through fire passages in the walls connecting the furnaces with the kiln proper. The top of the kiln is also paved with smooth, hard bricks, laid so as to form a close cover that can be opened or closed as desired. The bricks are piled in the same way as described above, the arches being left opposite the furnaces. With these improvements the bricks can be much more evenly burned and with a less consumption of fuel. The burning of a kiln of brick requires about a week. After the fires have been burning a sufficient length of time they are permitted to go out, and all the outside openings tightly closed to keep out the cold air, and thus allow the bricks to cool gradually. It requires much skill and practice to burn a kiln of bricks successfully.

223. *Down-draft Kilns.*—Kilns of this class require permanent walls and a tight roof. The floor must be open and connected by flues with a chimney or stack. These kilns are more often made circular in plan and in the shape of a beehive, although they are also made of a rectangular shape. The heat is generated in ovens built outside of the main walls, and the flames and gases enter the kiln through vertical flues, carried to about half the height of the kiln. The heat, therefore, practically enters the kiln at the top and being drawn downward by the draft produced by the chimney, passes through the pile of bricks and the openings in the floor into the flues beneath, and hence to the chimney or shaft. It is claimed that all kinds of clay wares may be burnt more evenly in down-draft kilns, and terra cotta and pottery are almost always burnt in such kilns. For terra cotta and pottery the beehive shape is generally used, several kilns being connected with one stack.

224. *Continuous Kilns.*—These kilns derive their name from the fact that the heat is continuous and the kilns are kept continuously burning. Continuous kilns are very different, both in construction and working, from the other two styles, and are also very expensive to construct. There are various styles of continuous kilns, each being protected by letters patent.

The most common type is that of two parallel brick tunnels connected at the ends. The outer walls are sometimes 8 feet thick at the bottom and 4 feet thick at the top. Various flues are built in these walls. The coal in continuous kilns is put in from the top. The bricks are piled in the kilns in sections, the sections being separated by paper partitions, and each section is provided with about four openings in the top for putting in the coal. After the kiln is started one section at a time is kept burning, and the heated gases are drawn through the next section so as to dry the bricks in that section before burning. There are often twenty or more sections in one kiln, and while one section is being burnt and others dried, others are being filled and others are cooling or being emptied.

Continuous kilns require a powerful draft to make them work successfully ; this draft is generally provided by a tall stack.

The principal advantages claimed for the continuous kiln are that it takes less fuel to burn the bricks, and a greater percentage of No. 1 bricks are obtained than in other kilns. The question of the kind of kiln to be used, however, is principally one of economy to the manufacturer, as it makes no particular difference to the architect in what kind of a kiln the brick are burnt.

225. Glazed and Enameled Brick.—These terms are used to designate bricks that have a glazed surface, the term "enameled" being applied indiscriminately to all bricks having such a surface.

There is, however, quite a difference between a glazed brick and an enameled brick. The true enamel is fused into the clay without an intermediate coating, and the enamel is opaque in itself, whereas a glaze is produced by first covering the clay with a "slip" and then with a second coat of transparent glaze resembling glass.

In the manufacture of glazed bricks the unburnt brick is first coated on the side which is to be glazed with a thin layer of "slip," which is a composition of ball clay, kaolin, flint and feldspar. The slip adheres to and covers the clay, and at the same time receives and holds the glaze. The glaze is put on very thin, and is composed of materials which fuse at about the temperature required to melt cast

iron, and leaves a transparent body covering the white slip. With a glazed brick it is the slip that gives the color of the brick, and as the slip covers the brick, the latter may be either red or white. Not all bricks, however, are suitable for glazing.

Enameled bricks are made from a particular quality of clay, generally containing a considerable proportion of fire clay. The enamel may either be applied to the unburnt brick or to the brick after it is burnt. The latter method, it is claimed, produces the most perfect brick.

In burning, the enamel fuses and unites with the body of the brick, but does not become transparent, and therefore shows its own color.

The manufacture of a true enameled brick is a much more expensive operation than that of making a glazed brick, besides being a very difficult operation. For this reason the glazed process is the one most generally employed, both in this country and in England.

It is claimed that an enameled brick is more durable than a glazed brick and will not so readily chip or peel. The enamel is also the purest white.

An enameled surface may be distinguished from one that is simply glazed by chipping off a piece of the brick. The glazed brick will show the layer of slip between the brick and the glaze, while an enameled brick will show no line of demarkation between the body of the brick and the enamel.

After the brick are in the wall none but an expert can distinguish between the two. Probably most of the so-called enameled bricks that have been used in this country are really glazed.

The bricks are, of course, enameled or glazed only on one face, or on one face and one end. The color is generally white, although light blue and some other colors can be obtained.

Until within a very few years nearly all the glazed bricks used in this country were imported from England, but there are now some eight or more factories in this country making them, and they produce more than half the glazed bricks now used in the United States.

Enameled bricks generally differ in size from the ordinary bricks. The size of the English brick is 3 inches by 9 inches by $4\frac{1}{2}$ inches. Part of the American factories adhere to the English size, while others make the regular American size.

The market price in Chicago for American and English glazed and enameled brick at the present time is $120 to $125 per M. for English brick and $90 to $110 for American brick.

The American glazed bricks are now more nearly perfect than when first put on the market, and appear to be giving satisfaction.

The true enameled brick is just as good for external as for interior use. It will stand the most severe and climatic changes, and may be used in any climate and any situation. It is also fireproof.

Both glazed and enameled bricks reflect light, acquire no odor, are impervious to moisture and form a finished and highly ornamental surface.

Use.—Glazed bricks, on account of the above properties, are very desirable for facing the walls of interior courts, elevator shafts, toilet rooms, etc., and especially for use in hospitals. They may also be used with good effect in public waiting rooms, corridors, markets, grocery and butter stores, and wherever a clean, light and non-absorbent surface is desired, and also one that will stand drenching with water.

226. Paving Bricks.—The introduction of brick paving for streets has led to the manufacture of this class of brick on an extensive scale.

Paving bricks do not strictly come within the province of the architect, but as he may have occasion to use such bricks for paving driveways, etc., it is well to know something about them.

Thin paving brick are also sometimes used for paving flat roofs of office buildings, apartment houses, etc.

Paving bricks are most commonly made by the stiff clay process, and the bricks, after being cut from the bar, are generally, although not always, repressed to give them a better shape. The clay used for making these bricks is generally shale, almost as hard as rock, although it is sometimes found in a semi-plastic condition. With the shale a certain proportion—often 30 per cent.—of fire clay is generally added.

The principal difference in the manufacture of paving brick from common building brick is in the burning. Paving brick, to stand the frost and wear, must be burnt to vitrification, or until the particles of the body have been united in chemical combination by means of heat. Besides being vitrified paving brick are also *annealed*, or toughened, by controlling the heat and permitting the bricks to cool under certain conditions.

Paving bricks, to enable them to endure the various sources of wear and disintegration to which they must be exposed in a street or driveway, or even on a roof, must be homogeneous and compact in texture, and must possess the qualities of vitrification and

toughness. They should be free from loose lumps or uncrushed clay, or from extensive laminations, or fine cracks or checks of more than superficial character or extent, and should not be so distorted as to lay unevenly in the pavement. They should be free from lime or magnesia in the form of pebbles, and should show no signs of cracking or spalling after remaining in water ninety-six hours. They should have a crushing strength of not less than 8,000 pounds per square inch.*

The best test of vitrification is that of porosity. A common hard-burnt brick may be very dense and strong and still absorb 10 or 15 per cent. of water. The same brick when vitrified will hold very little water, and should absorb none, in the chemical sense of the word.

Engineers, when specifying brick for pavements, generally limit the absorption to 4 per cent., and sometimes to 2 per cent., the brick to be first dried to 212° F. Paving bricks are made that do not absorb more than 1 per cent. It is claimed, however, that a brick may be vitrified and still absorb as high as 6 or 8 per cent., owing to its containing considerable air spaces. The density or specific gravity also gives a valuable idea of the degree of vitrification of paving brick. A great density or high specific gravity usually indicates durability.

For testing the toughness and resistance to wear under the horses' feet a machine called a "rattler" is used. The rattler resembles a barrel, and into it several bricks are put together with pieces of scrap iron and the rattler is then revolved rapidly for a given length of time. The amount that the bricks lose in weight is taken as the test of their durability.

It is claimed by good authorities that the rattler test when properly conducted is the most important test for durability, and that any brick which will successfully withstand this test will be found satisfactory.

227. Fire Bricks.—Fire bricks are used in places where a very high temperature is to be resisted, as in the lining of furnaces, fireplaces and tall chimneys. The ordinary fire brick used for the above purposes is made from a mixture of about 50 per cent. raw flint clay and 50 per cent. plastic clay, the proportion varying with different manufacturers. The bricks are made both by the stiff mud and dry press processes, and also by the soft mud process with hand moulding. It is claimed that the last process gives the most perfect brick.

* H. A. Wheeler, E. M., in the *Clay Worker*, August, 1895.

Fire bricks, to admit of rapid absorption or loss of heat, should be open grained or porous, and at the same time free from cracks. They should also be uniform in size, regular in shape, homogeneous in texture and composition, easily cut and infusible.

Fire bricks are generally larger than the ordinary building brick.

228. Classes of Building Brick.—*Common Brick.*—This term includes all those brick which are intended simply for constructional purposes, and with which no especial pains are taken in their manufacture. There are three grades of common brick, determined by their position in the kiln.

Arch or hard brick are those just over the arch, and which, being near the fire, are usually heated to a high temperature and often vitrified. They are very hard, and if not too brittle are the strongest brick in the kiln. They are often badly warped, so that they can only be used for footings and in the interior of walls and piers.

Red or well-burned brick should constitute about half the brick in the ordinary up-draft kiln, and when made of clay containing iron should be of a bright red color. For general purposes they constitute the best brick in the kiln.

Salmon or soft brick are those which form the top of the kiln and are usually underburned. They are too soft for heavy work or for piers, though they may be used for filling in light walls and for lining chimneys.

The strength and hardness of common bricks of all grades vary greatly with the locality in which they are made on account of the difference in the clay. Some of the salmon brick of New England are fully as hard and strong as the red bricks of other localities, particularly in the West. As the color of a brick may be due more to the presence or absence of iron than to the burning, it cannot be used as an absolute guide to the quality of the brick.

Stock brick are a handmade brick intended for face work, and with which greater care is taken in the manufacture and burning than with common brick. In the East they are sometimes called *face* brick.

Pressed brick or face brick generally refers to brick that are made in a dry press machine, or that have been repressed. They are usually very hard and smooth, with sharp angles and corners and true surfaces; they may be either stronger or weaker than common brick, according to the character of the clay and the degree to which they are burnt. Pressed brick are not usually burnt as hard as common brick, and are, therefore, sometimes not as durable. Pressed

brick cost from two to five times as much as common brick, and are, therefore, generally used only for the facing of the wall.

Moulded, arch and circle brick are special forms of pressed brick. A great variety of moulded or ornamental bricks are now made, by means of which mouldings and cornices may be built entirely of brick. Most of the companies manufacturing pressed bricks will also make any special shape of brick from an architect's designs. Arch bricks are made in the form of a truncated wedge and are used for the facing of brick arches. They can be made for any radius desired. Circle brick are made for facing the walls of circular towers, bays, etc. The radius of the bay should be given when ordering these brick.

229. Color of Bricks.—The color of common bricks depends largely upon the composition of the clay used and the temperature to which they are burnt. Pure clay, free from iron, will burn white, but the color of white bricks is generally due to the presence of lime. Iron in the clay produces a tint which varies from light yellow to orange and red, according to the proportion of iron contained in the clay. A clear bright red is produced by a large proportion of oxide of iron, and a still greater proportion of iron gives a dark blue or purple color, and when the bricks are intensely heated the iron melts and runs through the bricks, causing vitrification and giving increased strength. The presence of iron and lime produces a cream or light drab color. Magnesia produces a brown color, and when in the presence of iron makes the brick yellow.

The color of pressed brick is, of course, the same as that of common bricks made from the same clay; but pressed bricks are also colored artificially, either by mixing together clays of different chemical composition, or by mixing mineral paints or mortar colors with the clay in the dry pan. Bricks are also sometimes colored by applying a mineral pigment to the face of the bricks before burning. This latter method, however, is not very satisfactory. At the present time the use of colored bricks is very popular, and face brick are made in all shades of red, pink, buff, cream and yellow. Some of these colors are very effective when used in an artistic manner, but the use of colored bricks has been much abused, and it requires a fine sense of color to use them effectively, especially where two or more shades are used in the same building.

230. Size and Weight of Building Bricks.—In this country there is no legal standard for the size of bricks, and the dimensions vary with the maker and also with the locality. In the New

England States the common brick averages about $7\frac{3}{4}$x$3\frac{3}{4}$x$2\frac{1}{4}$ inches. In most of the Western States common bricks measure about $8\frac{1}{2}$x$4\frac{1}{8}$x$2\frac{1}{2}$ inches, and the thickness of the walls measures about 9, 13, 18 and 22 inches for thicknesses of 1, $1\frac{1}{2}$, 2 and $2\frac{1}{2}$ bricks. The size of all common bricks varies considerably in each lot, according to the degree to which they are burnt; the hard bricks being from $\frac{1}{8}$ to $\frac{3}{16}$ of an inch smaller than the salmon bricks.

Pressed brick or face brick are more uniform in size, as most of the manufacturers use the same size of mould. The prevailing size for pressed brick is $8\frac{3}{8}$x$4\frac{1}{8}$x$2\frac{3}{8}$ inches. Pressed bricks are also made $1\frac{1}{2}$ inches thick and 12x4x$1\frac{1}{2}$ inches, the latter size being generally termed Roman brick, or tile.

Pressed bricks should be made of such size that two headers and a joint will equal one stretcher, and it is also desirable that the length of a brick should be equal to three courses of bricks when laid. The National Brickmakers' Association in 1887 and the National Traders' and Builders' Association in 1889 adopted $8\frac{1}{4}$x4x$2\frac{1}{4}$ inches as the standard size for common bricks, and $8\frac{3}{8}$x$4\frac{1}{8}$x$2\frac{1}{4}$ for face bricks.

As all bricks shrink more or less in burning, it is generally necessary to assort even pressed bricks into piles of different thicknesses in order to get first-class work.

The weight of bricks varies considerably with the quality of the clay from which they are made, and also of course with their size. Common bricks average about $4\frac{1}{2}$ pounds each, and pressed bricks vary from 5 to $5\frac{1}{2}$ pounds each.

231. Requisites of Good Brick.—1. Good building brick should be sound, free from cracks and flaws and from stones and lumps of any kind, especially lumps of lime.

2. To insure neat work the bricks must be uniform in size and the surfaces true and square to each other, with sharp edges and angles.

3. Good bricks should be quite hard and burnt so thoroughly that there is incipient vitrification all through the brick. A sound, well-burnt brick will give out a ringing sound when struck with another or with a trowel. A dull sound indicates a soft or shaky brick. (This is a simple and generally sufficient test for common bricks, as a brick with a good ring is ordinarily sufficiently strong and durable for any ordinary work.)

4. A good brick should not absorb more than one-tenth of its weight of water. The durability of brickwork that is exposed to the action of water and frost depends more largely upon the absorptive power of the bricks than upon any other condition; hence, other

conditions being the same, those bricks which absorb the least amount of water will be the most durable in outside walls and foundations. As a rule the harder a brick is burnt the less water it will absorb. "Very soft, underburned bricks will absorb from 25 to 35 per cent. of their weight of water. Weak, light red ones, such as are frequently used in filling in the interior of walls, will absorb about 20 to 25 per cent., while the best bricks will absorb only 4 or 5 per cent. A brick may be called good which will absorb not more than 10 per cent." *

232. Strength.—A good brick, suitable for piers and heavy work, should not break under a crushing load of less than 4,000 pounds per square inch; any additional strength is not of great importance, provided the brick meets the preceding requirements. In a wall the transverse strength is usually of more importance than the crushing strength. For a good brick the modulus of rupture should not be less than 720 pounds; or, in other words, a brick 8 inches long, 4 inches wide and $2\frac{1}{4}$ inches thick should not break under a centre load of less than 1,620 pounds, the brick laying flatways and having a bearing at each end of 1 inch and a clear span of 6 inches. A first-class brick should carry 2,250 pounds in the centre without breaking, and bricks have been tested which carried 9,700 pounds before breaking.

BRICKWORK.

233. To build any kind of a brick structure so as to make a strong and durable piece of work, it is necessary to have a bed of some kind of mortar between the bricks. Brickwork, therefore, consists both of bricks and mortar, and the strength and durability of any piece of work will depend upon the quality of the bricks, the quality of the mortar, the way in which the bricks are laid and bonded and whether or not the bricks are laid wet or dry.

The strength and stability of a wall, arch or pier also depends upon its dimensions and the load it supports, but for the quality of the brickwork only the above items need be considered.

The kinds and qualities of mortars used for laying brickwork are described in Chapter IV. The majority of the brick buildings in this country are built with common white lime mortar, to which natural cement is sometimes added. For brickwork below ground either hydraulic lime or cement mortar should be used. (See Sections 107 and 127.)

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* Ira O. Baker, in "Masonry Construction," p. 38.

The function of the mortar in brickwork is threefold, viz.:

1. To keep out wet and changes in temperature by filling all crevices.

2. To unite the whole into one mass.

3. To form a cushion to take up any inequalities in the bricks and to distribute the pressure evenly.

The first object is best attained by grouting, or thoroughly "flushing" the work; the second depends largely upon the strength of the mortar, and the third is affected principally by the thickness of the joints.

234. Thickness of Mortar Joints.—Common brick should be laid in a bed of mortar at least $\frac{3}{16}$ and not more than $\frac{3}{8}$ of an inch thick, and every joint and space in the wall not occupied by other materials should be filled with mortar. The best way of specifying the thickness of the joint is by the height of eight courses of brick measured in the wall. This height should not exceed by more than 2 inches the height of eight courses of the same brick laid dry.

As common bricks are usually quite rough and uneven, it is not always easy to determine the thickness of a single joint, but the variation from the specifications in any eight courses that may be selected should be very slight. It is not uncommon to see joints $\frac{3}{4}$ inch thick in common brickwork, especially where the work is not superintended.

Pressed bricks, being usually quite true and smooth, can be laid with a $\frac{1}{8}$-inch joint, and it is often so specified. A $\frac{3}{16}$-inch joint is probably stronger, however, as it permits filling the joint better.

235. Laying Brick.—A. *Common Brick.*—The best method of building a brick wall is to first lay the two outside courses by spreading the mortar with a trowel along the outer edge of the last course of brick to form a bed for the brick to be laid, and scraping a dab of mortar against the outer vertical angle of the last brick laid, and then pressing the brick to be laid into its place with a sliding motion, which forces the mortar to completely fill the joint.

Having continued the two outer courses of brick to an angle or opening, the space between the courses should be filled with a thick bed of soft mortar and the bricks pressed into this mortar with a downward diagonal motion, so as to press the mortar up into the joints. This method of laying is called "shoving." If the mortar is not too stiff, and is thrown into the wall with some force, it will completely fill the upper part of the joints, which are not filled by the shoving process. A brick wall laid up in this way will be very

strong and difficult to break down. A very common method of laying the inside brick in a wall is to spread a bed of mortar and on this lay the dry brick. If the bricks are laid with open joints and thoroughly slushed up it makes very good work, but unless the men are carefully watched the joints do not get filled with mortar, and the wall will not be as strong as when the bricks are shoved.

236. *Grouting.*—Another method of laying the inside brick is to lay them dry on a bed of mortar, as described above, and then fill all the joints full of very thin mortar. This is called *grouting*, and, while it is condemned by many writers, the author knows from actual experience that when properly done it makes very strong work. No more water than is necessary to make the mortar fill all the joints should be used, and grouting should not be used in cold or freezing weather. Grouting is especially valuable when very porous bricks are used. (See Section 132.)

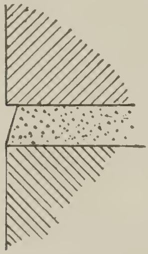


Fig. 122.

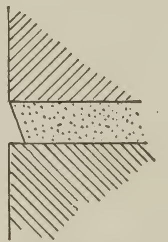


Fig. 123.

237. *Striking the Joints.*—For inside walls that are to be plastered the mortar projecting from the joints is merely cut off flush with the trowel. For outside walls and inside walls, where the brick are left exposed, the joint should be "struck" as in Fig. 122. This is done with the point of the trowel, by holding the trowel obliquely. Fig. 123 is the easiest joint to make, and is the one generally made unless Fig. 122 is insisted on. For inside work it makes no particular difference which joint is used, but for outside work Fig. 122 is much more durable, as the water will not lodge in the joint and soak into the mortar, as will be the case when the joint is made as in Fig. 123.

When "struck joints" are desired they should always be specified, otherwise the brick mason may claim that he is not obliged to strike them.

B. **Face Brick.**—Face brick are usually laid in mortar made of lime putty and very fine sand, often colored with a mineral pigment.

(See Sections 104 and 148.) The joints should not exceed $\frac{3}{16}$ of an inch, except in cases where a horizontal effect is desired, when the horizontal joints are made $\frac{1}{4}$ of an inch and the vertical joints as close as possible. For very fine work the joints are sometimes kept down to $\frac{1}{8}$ of an inch. The joints should be carefully filled with mortar and either ruled at once with a small jointer or else raked out and left for pointing. In very particular work a straight-edge is held under the joint and the jointer drawn along on top of it, thus making a perfectly straight joint. This is called *rulled* work. In laying the soffits of arches and vaults with face brick the joint cannot be finished until the centre is removed, therefore the joint should not be quite filled with mortar, and must be raked out and pointed after the centre is removed

Many pressed brick and some handmade bricks have one or more depressions in the larger surfaces of the brick to give a better key to the mortar. When the depressions are only on one side of the brick that side should be uppermost.

When building of face brick a piece of brickwork at least 2 feet high and 2 feet 6 inches long should be built up in an out-of-the-way place as soon as the first lot of brick is delivered, as a sample piece, and all stone or terra cotta work should be made to conform absolutely to the brickwork.

Sorting.—Pressed brick, even from the same kiln, generally vary in size and shade, the darker brick often being $\frac{1}{16}$ inch thinner than the lighter brick and also shorter. If, therefore, a perfectly uniform color is desired the bricks must be sorted into piles, so that each lot will be of the same shade, and each shade laid in the building by itself. The change between the different shades should occur, where possible, at a string course or at an angle in the building. Many architects, however, consider that a handsomer and brighter wall is secured by mixing the different shades, so that hardly two bricks of exactly the same shade will come together, although if the mixing is well done the general tone of the wall at a distance will be uniform. With colored bricks this haphazard method undoubtedly gives the most artistic and sparkling effect.

Circular Work.—For circular walls, faced with pressed brick, the bricks should be made of the same (or very nearly the same) curvature as the wall. Many pressed brick manufacturers carry circle brick of different curvatures in stock, and any curvature can be made to order.

When circle brick cannot be obtained straight bricks may be used for curvatures with a radius of 12 feet or over, and for lesser radii half brick or headers should be used.

238. Brick to be Wet.—Mortar, unless very thin, will not adhere to a dry, porous brick, because the brick robs the mortar of its moisture, which prevents its proper setting. On this account brick should *never* be laid dry, except in freezing weather, and in hot, dry weather it is impossible to get the bricks too wet. When using very porous brick the wetting of the brick is of more consequence in obtaining a strong wall than any other condition. As wetting the bricks greatly increases their weight and consequently the labor of handling them, besides making it harder on the hands, masons do not like to wet them unless they are obliged to, and it should always be specified and insisted upon by the superintendent, except in freezing weather.

Pressed brick cannot very well be laid dry, and the masons generally wet them for their own convenience, but they will often tell all sorts of stories to escape wetting the common brick.

239. Laying Brick in Freezing Weather. — Brickwork should never be laid when the temperature is below 32°, and if it is below 40° and liable to fall below 32° at night, salt should be mixed with the mortar and the bricks *heated* before laying, and the top of the wall covered with boards and straw at night. It is much better not to lay brick in freezing weather unless the delay occasioned involves a great loss. In building large buildings in the winter time one-third Portland cement should be added to the mortar, then it will not be damaged by freezing. It is necessary that the surface of the bricks be clean and free from frost, snow or ice, when they are laid, otherwise the mortar will not adhere to them.

If the mortar in the upper courses becomes frozen over night, those courses should be taken down and the bricks thoroughly cleaned before being used again. For the effect of freezing on mortar see Section 139.

Protection from Storms.—Wet without frost does not injure the strength of brickwork, but if rain strikes the top of a wall it will wash the mortar out of the joints and stain the face of the wall.

The excessive wetting of a wall is also injurious, as it takes a long time for the wall to dry out, and it is likely never to dry to a uniform color. For this reason the top of the wall should always be protected at night, or when leaving off work, by boards placed so as to shed the water.

240. Ornamental Brickwork.—The ornamental effects to be obtained by the varied use of bricks are exceedingly numerous. First, there are the constructive features, such as arches, impost courses, pilasters, belt and string courses, cornices and panels ; then there is a large field for design in surface ornament, by means of brick of different shades or color, laid so as to form a pattern.

For the constructive features both plain and moulded bricks may be used, although only very plain effects can be produced by plain brick alone.

In nearly all of our large cities, and especially those near which pressed brick are manufactured, a great variety of moulded bricks can be obtained, by means of which it is possible to construct almost any moulding, belt course, etc., that may be desired.

Belt courses and cornices, and in fact any moulded work built of brick, is much cheaper than the same mouldings cut in stone.

In designing brick details a point to be observed is that the projection should be kept small.

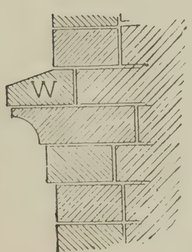


Fig. 124.

The top of all belt courses should have a wash on top, as shown in Fig. 124.

The top course, *W*, should be laid as stretchers when the projection is not over 3 inches to reduce the number of end joints, and the bricks should also be laid in cement mortar, so that the mortar in the end joints will not be washed out.

If *W* is a stretcher course, at least every other brick in the course below should be a header.

If a beveled brick cannot be obtained for the top course, and a plain brick must be used, its upper surface should be protected by sheet lead built into the second joint above it, as shown at *A*, Fig. 125, or the top of the bricks may be plastered with Portland cement, as shown at *B*. Unless some such precaution is taken to protect the top of the projecting brick from the wet, the rain water will after a while soften the mortar in the joint, *P*, and penetrate into the wall. The end joints in the belt course are always liable to be washed out.

Belt courses and cornices should always be well tied to the wall by using plenty of headers or iron ties. The top of the wall should also be well anchored to the rafters or ceiling joist by iron anchors, as the projection of the cornice tends to throw the wall outward.

In using moulded brick in string courses and cornices it is more economical to use bricks that can be laid as stretchers, as it, of

course, takes a less number of stretchers than of headers to fill a given length, and the bricks cost the same.

One of the greatest objections to brick mouldings is the difficulty of getting them perfectly straight and true. Nearly all moulded brick become more or less distorted in moulding and burning, so that when laid the abutting ends do not match evenly, and the moulding presents the appearance shown in Fig. 126.

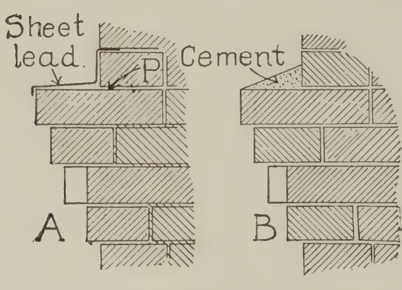


Fig. 125.

Some makes of brick, however, are quite free from these defects, and before selecting moulded bricks to be used in this way the architect should endeavor to ascertain which makes are the truest and give the most perfect work.

By being very careful in laying the bricks to average the defects, and by ruling the joints, the effect of the distortion may be largely overcome. Headers do not show the distortion as much as stretchers.

241. Cornices.—For brick buildings with a parapet wall and flat roof a brick cornice is generally the most appropriate unless one of terra cotta can be afforded. A brick cornice is certainly to be

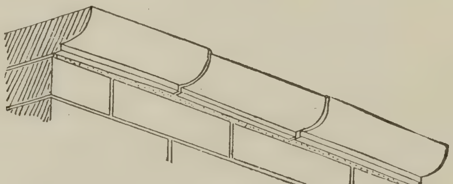


Fig. 126.

preferred to one of galvanized iron or wood, as it is more durable and will not require painting, besides being a more appropriate use of material.

In cornices where considerable projection is desired it is almost always safe to adopt some corbeled treatment, building the corbels up by slightly projecting each course. Dentil courses in cornices and string courses are also very effective and easy to lay.

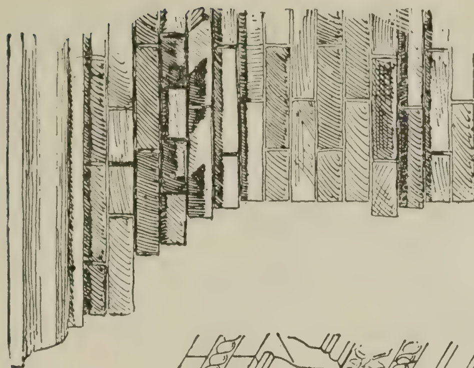


Fig. 129.

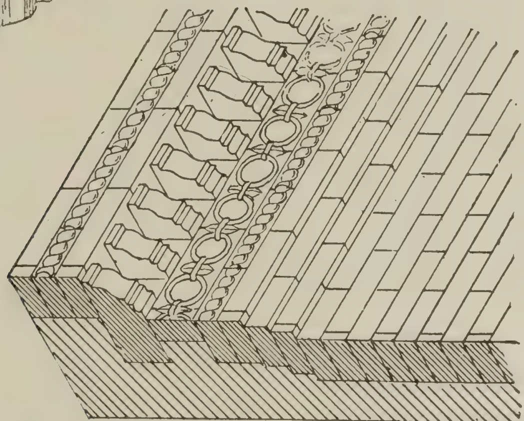


Fig. 128.

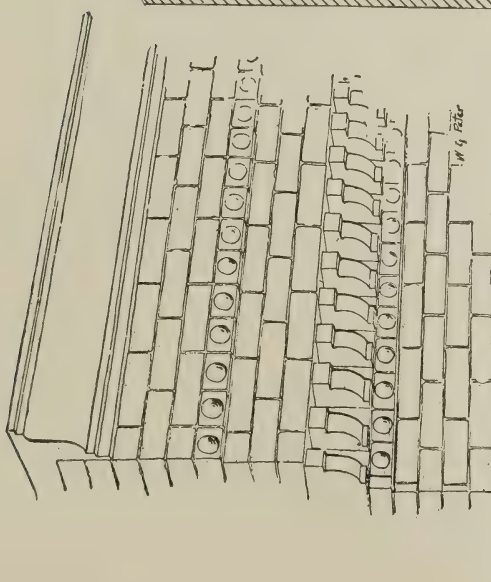


Fig. 127.

DESIGNS FOR BRICK CORNICES.

[From the *Brickbuilder*.]

Figs. 127 and 128 are suggestions for moulded brick cornices for three and four-story buildings, and Fig. 129 one of plain bricks for a two-story building with a low pitch roof. Fig. 130 shows a section of a simple brick cornice that the author has used on brick churches having a pitch roof.

Decorative brickwork should always be executed in smooth, regular brick of even color, as uneven colors and rough brick mar the effect of light and shade and detract from the design.

All brick walls or cornices should be capped by a projecting coping of metal, terra cotta or stone, provided with a hollow drip to throw off the water.

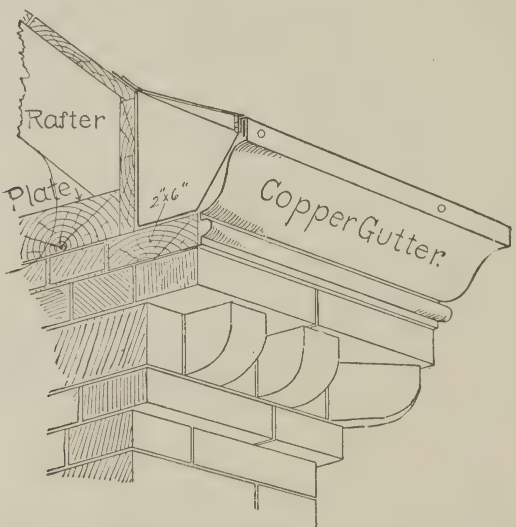


Fig. 130.

For brick cornices a copper or galvanized iron crown mould, such as is shown in Figs. 127 and 129, is very appropriate. The metal should be carried over the top of the wall (if a parapet) and down 5 inches at the back.

If the wall terminates as shown in Fig. 128 the upper courses should be laid in cement mortar and the top well plastered with Portland cement. This will protect the wall for several years, but is not as lasting as terra cotta or metal.

242. Surface Patterns.—Surface patterns, or diaper work, are very common in brick buildings in Europe, and they have lately been introduced to a considerable extent in this country.

Their chief object is to give variety to a plain wall space. When used in exterior walls they should not be so marked as to make the pattern insistent and thus interfere with other features of the building.

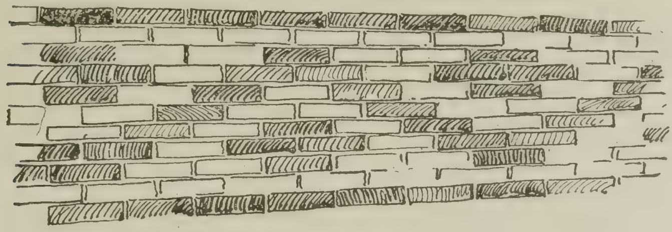


Fig. 131.

Usually sorting the brick into light and dark shades, or varying the color of the mortar in which the pattern is laid, will be sufficient for any surface decoration, the best success in this class of decoration being obtained by using comparatively simple designs and quiet contrasts of color.

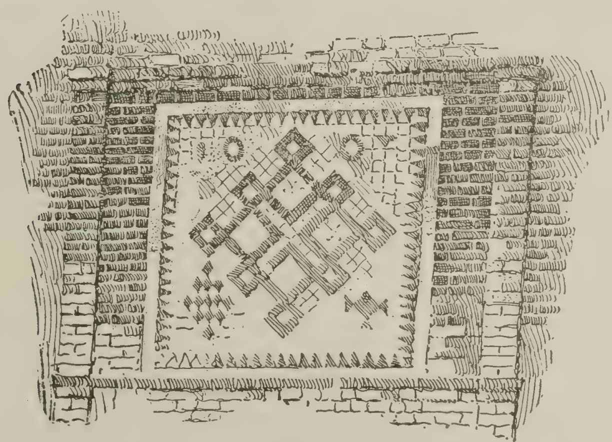


Fig. 132.

If different colors are used the greatest care must be exercised in their selection, and even with care and thought it is not granted to all architects to use color nicely.

One of the best opportunities for the use of color lies in the direction of pattern work for frieze and band courses.

Fig. 131 shows a simple brick diaper for a frieze, and Figs. 132 and 133 an ornamental panel and chimney, the latter designed by Mr. H. P. Marshall, architect.

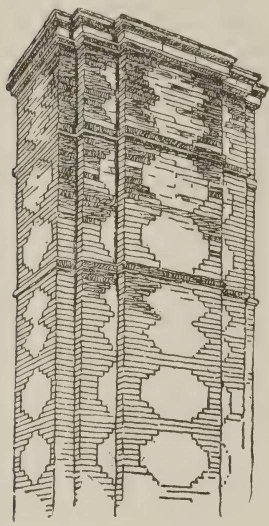


Fig. 133.

Surface patterns should generally be flush with the wall. When used as in Fig. 133 the pattern may project $\frac{1}{4}$ inch from the surface or panels.

Diaper work may also be used with good effect on interior brick walls of waiting rooms, corridors, public baths, etc.

CONSTRUCTION OF WALLS.

243. The proper construction of a brick building involves many things besides the mere laying of one brick on top of another with a bed of mortar between. The manner of laying or bedding the bricks and the general methods of doing the work having been considered, we will next consider the points in construction required to obtain a strong and durable wall, and the precautions to be observed to prevent settlements and cracks and adapting the work to the purposes for which it is intended.

Aside from the quality of the materials and the character of the work, the bonding of a wall has the most to do with its strength.

Bond.—Bond in brickwork is the arrangement of the bricks adopted for tying all parts of the wall together by means of the

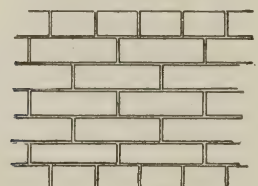


Fig. 134.—Common Bond.

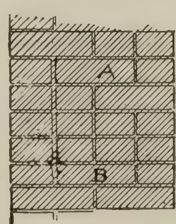
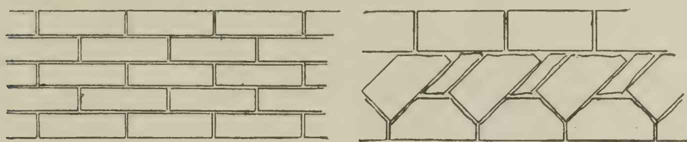


Fig. 135.

weight resting on the bricks, and also for distributing the effects of a concentrated weight over an ever-increasing area.

Common Bond.—A brick laid with its side parallel to the face of the wall is called a *stretcher;* when laid at right angles to the wall,

so that its end is parallel to the face of the wall, it is called a *header.* Common brick walls in this country are almost universally built by laying the brick all stretchers for from four to six courses and then laying a course of headers as shown in Fig. 134. When the wall is more than one brick in thickness the heading courses should be arranged either as at *A* or *B*, Fig. 135. For first-class work the wall should be bonded with a heading course every sixth course.



A *B*

Fig. 136.—Plumb Bond.

244. *Plumb or diagonal bond* (sometimes called American bond) is generally used when the wall is faced with pressed brick. The face brick are laid all stretchers with the joints plumb above each other from bottom to top of the wall, as shown at *A*, Fig. 136. The bonding of the face brick to the common brick is accomplished by clipping off the back corners of the face brick in every sixth or seventh course and laying diagonal headers behind, as shown at *B*, Fig. 136. This does not make as strong a tie as a regular header, but if carefully done it appears to answer the purpose. Very often where this bond is used only one corner of each face brick in the outside course is clipped, so that only half as many diagonal brick, or headers, as are indicated in Fig. 136 are used.

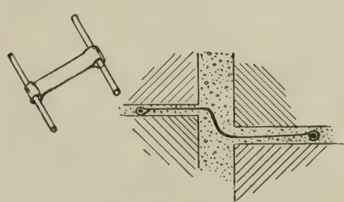


Fig. 137.

This of course does not make as strong a bond as when both of the back corners are clipped. In walls exceeding one story in height the architect should see that both corners are clipped. The strongest method of bonding for face brick is by the Flemish or cross bond, described in Section 245. The objection to these bonds, however, is the increased expense occasioned by using so many face brick headers and also that the face brick and common brick do not usually lay to the same heights, so that it would be necessary to clip the common brick if face brick headers were used in every course, or even every third or fourth course.

Face bricks, when laid as in Fig. 136, are often tied to the backing by pieces of galvanized iron or tin (as shown in Fig. 137), which have their ends turned over a stiff wire about 4 inches long. The wire is not absolutely essential, but should always be used in first-

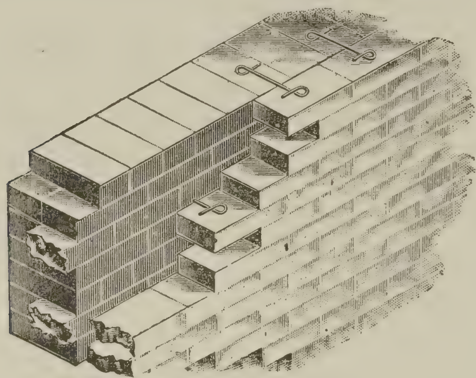


Fig. 138.

class work. A still better tie for bonding face brick to the backing is the Morse Wall Tie, shown in Fig. 138.

This tie is made from $\frac{5}{32}$ and $\frac{1}{8}$-inch galvanized steel wire 7, 9, 12 and 16 inches in length. The $\frac{5}{32}$-inch wire is used for ordinary pressed brickwork, and the $\frac{1}{8}$-inch size for very closely laid work. It is now very extensively used in the Eastern portion of the country.

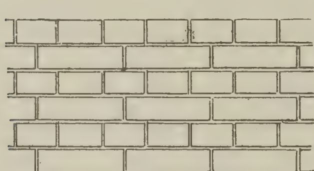


Fig. 139.—English Bond.

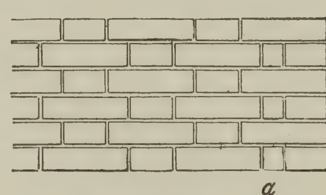


Fig. 140.—Flemish Bond.

One advantage obtained in using the metal tie is that it is not necessary that the joints in the face work and backing shall be on the same level, as the ties can be bent to conform to the difference in level, as shown in Fig. 137. Face brick bonded in this way should be tied at least every fourth course with one tie to each face brick.

245. *English bond* (Fig. 139) is a method of bonding much used in England, and consists of alternate heading and stretching courses.

It is probably the strongest method of bonding common brick, but it is not applicable where face brick are used. It does not make very attractive work, and is scarcely ever used in this country.

Flemish bond, shown in Fig. 140, consists of alternate headers and stretchers in every course, every header being immediately over the centre of a stretcher in the course below ; closers (*a*) are inserted in alternate courses next to the corner headers to give the lap. This makes a very strong bond, but cannot be used with face brick unless the common brick are a little smaller than the face brick, so as to lay up even courses. A modification of this bond, consisting of laying every fifth course of alternate headers and stretchers, is sometimes adopted. It makes stronger work than the diagonal bond and looks about as well.

English cross bond is a variety of English bond said to be much used in Holland, its name being suggested by the appearance of the surface, on which the bricks seem to arrange themselves into St. Andrew's crosses. It only differs from ordinary English bond in that the stretchers of the successive stretching courses break joint with each other on the face of the wall, as well as with the headers in the adjoining courses, as shown in Fig. 141. This makes a much better looking wall than the ordinary English bond.

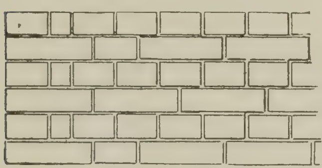


Fig. 141.—Cross Bond.

246. Hoop Iron Bond.—Pieces of hoop iron are often laid flat in the bed joints of brickwork to increase its longitudinal tenacity and prevent cracks from unequal settlement. The ends of the iron should be turned down about 2 inches and inserted into the vertical joints. Nothing less than No. 18 iron should be used, and the holding power of the ties may be greatly improved by dipping in hot tar and then covering with sand. Hoop iron bond is strongly to be recommended for strengthening brick arches and the walls above, also the walls of towers, etc., and where an interior wall joins an external wall. Twisted iron bars are still better for this purpose.

247. Anchoring the Wall.—Although this belongs more especially in the carpenter work, it is mentioned here as a very important point in securing the stability of the wall and preventing its inclining outward.

Brick walls should be tied to every floor at least once in every 6 lineal feet, either by iron anchors, solidly built into the wall and spiked to the floor joist, or by means of a box anchor or joist hanger.

The forms of iron anchors most commonly used for this purpose are those shown in Fig. 142, the one shown at *a* being the most common, and about as good a style as any. The anchor shown at *b* answers equally as well, but costs a very little more. Anchors like *a* and *b* are spiked to the sides of the floor joist and built into the wall, as shown in Fig. 143.

If the wall is a side or rear wall, where the appearance is not of much consequence, it is better to have the anchor pass clear through the wall, with a plate on the outside, as such an anchor gets a much better hold on the wall than is possible when it is built into the middle of the wall. The cheapest form of anchor for this purpose is that shown at *c*, which has a thin plate of iron doweled and upset on the outer end. This style of anchor may also be used for building into the middle of the wall.

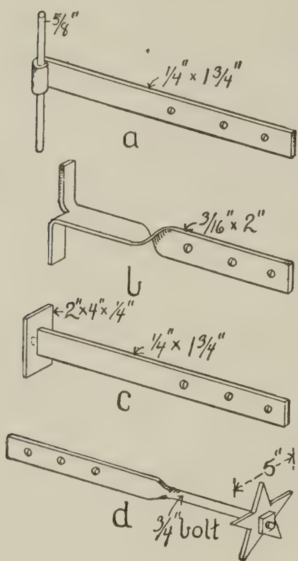


Fig. 142.

For anchoring the ends of girders, or where a particularly strong anchor is desired, the form shown at *d* is undoubtedly the best. This anchor is made from a $\frac{3}{4}$-inch bolt, flattened out for spiking to the joist and provided with a cast iron star washer. It possesses the advantage of having a nut on the outer end, which can be tightened up if desired after the wall is built.

All of these anchors should be spiked to the side of the joist or girder, *near the bottom*, as shown in Fig. 143. The nearer the anchor is placed to the top of the joist, the greater will be the destructive effect on the wall by the falling of the joist, as shown in Fig. 143 A.

For anchoring walls that are parallel to the joist the anchor must be spiked to the top of the joist, and should either be long enough to reach over two joist, or a piece of $1\frac{1}{4}$-inch board should be let into the top of three or four joist and the anchor spiked to it.

Any of these forms of anchors have the objection that in case the beams fall during a severe fire or from any other cause they are apt to pull the wall over with them. To overcome this objection, as well as to secure other advantages, the Duplex Wall Hanger, shown in Fig. 144, and the Goetz Box Anchor, shown in Fig. 145, have been

invented. These devices hold the timber by means of a rib or lug gained into its lower edge. The anchoring is not as efficient perhaps as is secured by the anchors shown in Fig. 142 but is ample for all ordinary conditions, especially as when these devices are used *every* joist is anchored.

These devices also offer the additional advantages that they do not weaken the wall, while they increase the bearing of the timbers and reduce the possibility of dry rot to a minimum. They also permit of easily replacing the joist after a fire.

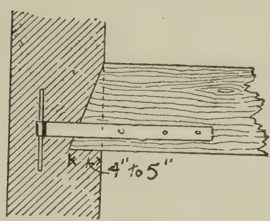


Fig. 143.

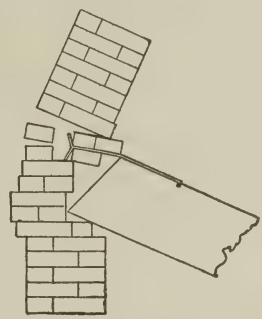


Fig. 143 A.

The Duplex Wall Hanger is especially desirable for party and partition walls, as it obviates the necessity of building the beams into the wall and permits the wall to be as solid at the floor levels as in other portions. (See Fig. 146.)

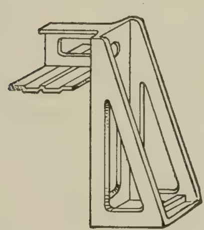


Fig. 144.

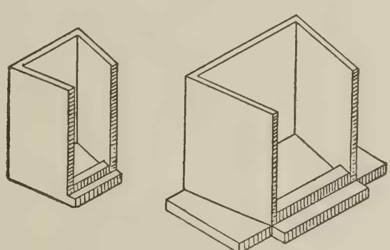


Fig. 145.

The importance of anchoring the joist to the walls, and thus preventing the walls from being thrown outward either from settlement in the foundation or from pressure exerted against the inside of the wall, is very great, and should not be overlooked by the architect. Many walls have either fallen, or had to be rebuilt, that might have been saved by proper anchoring.

248. Corbeling the Wall for Floor Joist.—In some localities it is the custom to form a ledge to support the floor joist by means of a continuous corbel of three or more courses. This is done to prevent weaking the wall by the ends of the floor timbers, for, of course, wherever wooden timbers are built into a wall they lessen the section or bearing area of the wall by just the amount of space taken up by the timbers, and in partition walls this is very considerable.

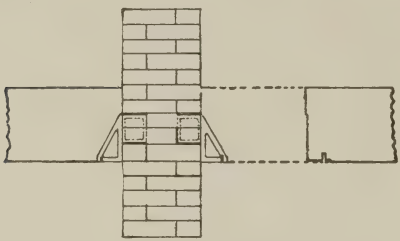


Fig. 146.

The Chicago Building Ordinance provides that all walls of warehouses, 16 inches or less in thickness, and all walls of dwellings, 12 inches or less in thickness, shall have ledges 4 inches wide to support the floor joist, and in all cases where ledges are built they are to be carried to the top of the joist, as shown in Fig. 147.

When walls are corbeled in this way it requires a plaster or wooden cornice, as shown by the dotted line, to give a proper finish for the angles of the rooms, and for this reason corbeling is not usually done where not required by law.

Corbeling for floor joist should not be attempted with soft or poor bricks.

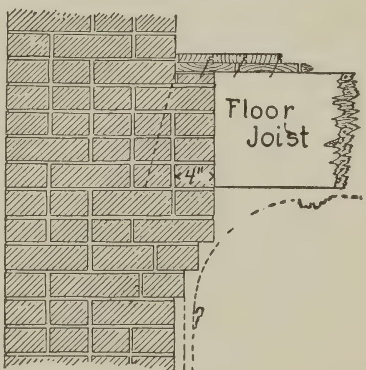


Fig. 147.

249. Walls to be Carried Up Evenly.—The walls of a building should be carried up evenly, no part being allowed to be carried up more than 3 feet above the rest, except where it is stopped by an opening. Building one part of a wall up ahead of the rest produces unequal settlement, and, the joints in the higher part setting before the rest is added to it, the work laid last is apt to settle away from the other and weaken the wall, besides marring the appearance of it. Whenever it is necessary to carry one part of a wall higher than the rest the end of the high part should be stepped or *racked* back, and not run up vertically, with only toothings left for connecting the rest of the work.

250. Bonding of Walls at Angles.—An important feature in the construction of brick buildings is the secure bonding of the front and rear walls to side or partition walls. When practicable both walls should be carried up together, so that each course of brick may be well bonded. If to avoid delay the side wall must be built up ahead of the front wall, the end of the side wall should be built with toothings, as shown in Fig. 148, eight or nine courses high, into which the backing of the front wall should be bonded. In addition to the brick bonding anchors made of $\frac{3}{8}$x2-inch wrought iron, with one end turned up 2 inches and the other welded around a $\frac{5}{8}$-inch round bar, should be built into the side wall about every 5 feet in height, as shown in the figure. The anchors should be of such length that the rod will be at least 8 inches in from the back of the front wall and extend at least 17 inches into the side wall. The building regulations of most of the larger cities require that all intersecting brick walls shall be tied together in this way.

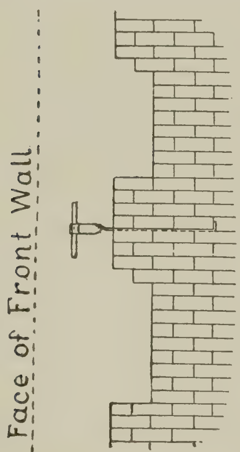


Fig. 148.

251. Openings in Walls.—The location of all door and window openings in brick walls should be carefully considered, not only as regards convenience, but also as to their effect on the strength of the wall. The combined width of the openings in any bearing wall should not much exceed one-fourth of the length of the wall, and as far as possible the openings in the different stories should be over each other. Especially avoid placing a window either under a pier or directly over a narrow mullion, as at *a* or *b*, Fig. 149. If windows must be used in these positions, steel beams should be placed over the windows *a* and *c*, as a stone lintel or brick arch would be quite sure to crack from the combined effects of the load and the settlement of the joints in the brickwork on either side of the window.

All openings in exterior walls should either have relieving arches or cast iron or steel beams behind the stone cap or face arches. Ordinary relieving arches (see Section 265) are commonly used where the width of the opening is less than 6 feet, and steel beams for greater widths. In bearing walls, where the top of the openings come within 12 inches of the bottom of the floor joist, it is hardly safe to use relieving arches, unless the floor loads are very light.

For door openings in unplastered brick partitions cast iron lintels may be used to good advantage, as they give a smooth, level soffit to the opening and show only a narrow strip of metal on the face of the wall.

252. Joining New Walls to Old.—When a new wall is to be joined to an old one, at right angles, a groove should be cut in the old wall similar to that shown in Fig. 118 for the new wall to fit into and to allow of its settling independently. A cheaper method, and one more commonly used in light work, is to nail a scantling, or 2x4, to the wall of the old building, so that it will come in the centre of the new wall, as shown in Fig. 150. A similar method can be used for jointing the ends of an old and new wall. New work should never be toothed to old work unless the new work is laid in cement.

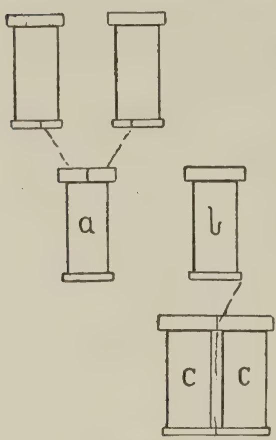


Fig. 149.

253. Thickness of Walls.—There is no practical rule by which it is possible to calculate the necessary thickness of brick walls, as the resistance to crushing, which is the only direct strain, is usually only a minor consideration.

We must therefore rely principally upon experience in determining the thickness of walls for any given building, unless the construction of the building is controlled by municipal or State regulations.

In nearly all of the larger cities of the country the minimum thickness of the walls is prescribed by law or ordinance, and as these requirements are generally ample they are usually adhered to by architects when designing brick buildings.

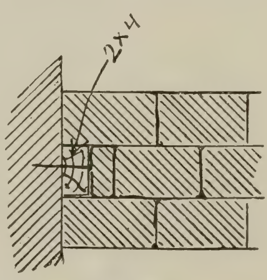


Fig. 150.

Table IX. gives a comparison of the thickness of walls required for mercantile buildings in the representative cities of the different sections of the United States, and affords about as good a guide as any to the young architect. Walls for dwellings are generally permitted to be 4 *inches less* than the thicknesses given in the table.

TABLE IX.—THICKNESS OF WALLS IN INCHES FOR WAREHOUSES, ETC.

HEIGHT OF BUILDING.		STORIES.											
		1st	2d	3d	4th	5th	6th	7th	8th	9th	10	11th	12th
Two Stories.	Boston . . .	16	12	...	...	...	...	...	...	...	...	...	...
	New York .	12	12	...	...	...	...	...	...	...	...	...	...
	Chicago . .	12	12	...	...	...	...	...	...	...	...	...	...
	Minneapolis	12	12	...	...	...	...	...	...	...	...	...	...
	Memphis . .	18	13	...	...	...	...	...	...	...	...	...	...
	Denver . .	13	13	...	...	...	...	...	...	...	...	...	...
Three Stories.	Boston . . .	20	16	16	...	...	...	...	...	...	...	...	...
	New York .	16	16	12	...	...	...	...	...	...	...	...	...
	Chicago . .	16	12	12	...	...	...	...	...	...	...	...	...
	Minneapolis	16	12	12	...	...	...	...	...	...	...	...	...
	Memphis .	22½	18	13	...	...	...	...	...	...	...	...	...
	Denver . . .	17	13	13	...	...	...	...	...	...	...	...	...
Four Stories.	Boston . . .	20	16	16	16	...	...	...	...	...	...	...	...
	New York .	16	16	16	12	...	...	...	...	...	...	...	...
	Chicago . .	20	16	16	12	...	...	...	...	...	...	...	...
	Minneapolis	16	16	12	12	...	...	...	...	...	...	...	...
	Memphis . .	27	22½	18	13	...	...	...	...	...	...	...	...
	Denver . . .	21	17	13	13	...	...	...	...	...	...	...	...
Five Stories.	Boston . . .	20	20	20	20	16	...	...	...	...	...	...	...
	New York .	20	16	16	16	16	...	...	...	...	...	...	...
	Chicago . .	20	20	16	16	16	...	...	...	...	...	...	...
	Minneapolis	20	16	16	12	12	...	...	...	...	...	...	...
	Memphis . .	31½	27	22½	18	13	...	...	...	...	...	...	...
	Denver . .	21	21	17	17	13	...	...	...	...	...	...	...
Six Stories.	Boston. . . .	24	20	20	20	20	16	...	...	...	...	...	...
	New York .	24	20	20	20	16	16	...	...	...	...	...	...
	Chicago . .	20	20	20	16	16	16	...	...	...	...	...	...
	Minneapolis	20	20	16	16	16	12	...	...	...	...	...	...
	Memphis . .	36	31½	27	22½	18	13	...	...	...	...	...	...
	Denver . . .	26	21	21	17	17	13	...	...	...	...	...	...
Seven Stories.	Boston . . .	24	20	20	20	20	20	16	...	...	...	...	...
	New York .	28	24	24	20	20	16	16	...	...	...	...	...
	Chicago . .	20	20	20	20	16	16	16	...	...	...	...	...
	Minneapolis	20	20	20	16	16	16	12	...	...	...	...	...
	Memphis . .	40½	36	31½	27	22½	18	13	...	...	...	...	...
	Denver . . .	26	21	21	21	17	17	17	...	...	...	...	...
Eight Stories.	Boston . . .	28	24	20	20	20	20	20	16	...	...	...	...
	New York .	32	28	24	24	20	20	16	16	...	...	...	...
	Chicago . .	24	24	20	20	20	16	16	16	...	...	...	...
	Minneapolis	24	20	20	20	16	16	16	12	...	...	...	...
	Memphis . .	45	40½	36	31½	27	22½	18	13	...	...	...	...
	Denver . . .	30	26	21	21	21	17	17	17	...	...	...	...
Nine Stories.	Boston . . .	28	24	24	20	20	20	20	20	16	...	...	...
	New York .	32	32	28	24	24	20	20	16	16	...	...	...
	Chicago . .	24	24	24	20	20	20	16	16	16	...	...	...
	Minneapolis	24	24	20	20	20	16	16	16	12	...	...	...
	Memphis . .	49½	45	40½	36	31½	27	22½	18	13	...	...	...
	Denver . . .	30	26	26	21	21	21	17	17	17	...	...	...
Ten Stories.	Boston . . .	28	28	24	24	20	20	20	20	20	16	...	...
	New York .	36	32	32	28	24	24	20	20	16	16	...	...
	Chicago . .	28	28	24	24	24	20	20	20	16	16	...	...
	Minneapolis	24	24	24	20	20	20	16	16	16	12	...	...
	Memphis . .	54	49½	45	40½	36	31½	27	22½	18	13	...	...
	Denver. . .	30	30	26	26	21	21	21	17	17	17	...	...

In compiling this table the top of the second floor was taken at 19 feet above the sidewalk, and the height of the other stories at 13 feet 4 inches, including the thickness of the floor, as the New York and Boston laws give the height of the walls in feet instead of in stories. When the height of stories exceeds these measurements the thickness of the walls in some cases will have to be increased.

The maximum height of stories permitted by the Chicago ordinance with these thicknesses of walls is 18 feet in first story, 15 feet in second story, 13 feet 6 inches in the third and 12 feet in the stories above.

Although there is a great difference in the thicknesses given in the table, more indeed than there should be, yet a general rule might be deduced from the table, for mercantile buildings over four stories in height, which would be somewhat as follows:

For brick equal to those used in Boston or Chicago make the *thickness of the three upper stories* 16 *inches*, of the next three below 20 inches, the next three 24 inches and the next three 28 inches. For a poorer quality of material make only the *two* upper stories 16 inches thick, the next three 20 inches and so on down.

In buildings less than five stories in height the top story may be 12 inches in thickness.

For the walls of dwellings, 13 inches and 9 inches may be used for two-story buildings; for three-story buildings the walls should be 13 inches thick the entire height above the basement, and for four-story buildings 17 inches in first story and 13 inches the entire height above.

In determining the thickness of walls the following general principles should be recognized:

First. That walls of warehouses and mercantile buildings should be heavier than those used for living or office purposes.

Second. That high stories and clear spans exceeding 25 feet require thicker walls.

Third. That the length of the wall is a source of weakness, and that the thickness should be increased 4 inches for every 25 feet over 100 or 125 feet in length. (In New York the thicknesses in the table must be increased for buildings exceeding 105 feet in depth. In the Western cities the tables are compiled for warehouses 125 feet in depth, as that is the usual depth of lots in those cities.)

Fourth. That walls containing over 33 per cent. of openings should be increased in thickness.

Fifth. Partition walls may be 4 inches less in thickness than the outside walls if not over 60 feet long, but no partition to be less than 8 inches thick.

PARTY WALLS.

There is much diversity in building regulations regarding the thickness of party walls, although they all agree in that such walls should never be less than 12 inches thick. About one-half of the laws require the party walls to be of the same thickness as external walls; the remainder are about equally divided between making the party walls 4 inches thicker or thinner than for independent side walls.

When the walls are proportioned by the rule previously given, the author believes that the thickness of the party walls should be increased 4 inches in each story. The floor load on party walls is obviously twice that on side walls, and the necessity for thorough fire protection is greater in the case of party walls than in other walls.

254. **Curtain Walls.**—In buildings of the skeleton type the outer masonry walls are usually supported either in every story or every other story by the steel framework, and carry nothing but their own weight. Such walls may, therefore, be considered as only one or two stories high, and are usually made only 12 inches thick for the whole height of a twelve or fifteen-story building.

255. **Wood in Walls.**—As a rule, no more woodwork should be placed in a brick wall than is absolutely necessary. Wooden lintels for supporting brick walls are objectionable not only on account of their being combustible, but also on account of their shrinkage. It is generally impossible to obtain framing lumber that is thoroughly dry, and when a brick wall is partially supported by a wooden lintel a crack is quite sure to develop sooner or later in the manner shown in Fig. 151. The crack is obviously caused by the shrinkage of the lintel, which permits the portion of the wall supported on it to settle by an amount equal to the shrinkage of the wood, while the portion of the wall *a*, being supported on the brick pier, does not settle.

Bond timbers, or pieces of studding laid under the ends of the floor joist, are also objectionable, for the reason that they are quite sure to shrink, and thus leave the wall above them unsupported. Bond timbers are very convenient for the carpenters, as they give a level bearing for the floor joist, and they also distribute the weight over the brickwork, but they should never be used in buildings over two

stories in height, or in walls less than 12 inches thick. If used at all they should be selected from the dryest lumber that can be obtained.

For the proper use of wooden lintels under relieving arches see Section 265.

Strips of wood are sometimes built into walls to form a nailing for the wood finish or for the furring strips. Such strips should not be used in buildings over two stories in height, and should not be over $\frac{3}{8}$ inch thick, so that they may take the place of the mortar joint.

Wooden bricks, or blocks of wood of the size of a brick, are also sometimes built into brick walls to provide nailings for furring strips, door frames, etc. These not only tend to weaken the wall, but they generally shrink so as to become loose, thereby losing their holding power. If the bricks are so hard that nails cannot be driven into them, and the mortar is too poor to hold the nails, then porous terra cotta blocks should be used for nailing strips in first-class work.

Porous terra cotta will hold a nail almost like a board, and has none of the objections common to wood.

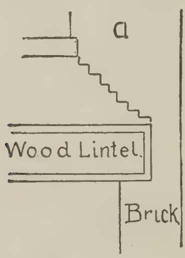


Fig. 151.

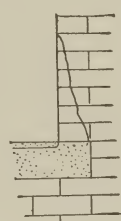


Fig. 152.

256. Cracks in Walls.—It is a very common thing to see cracks in brick walls. These cracks may be produced by either one of several causes.

Probably the most frequent cause of the cracking of masonry walls is the settlement of the foundations, either from their being improperly designed or from the settlement of the ground caused by wet. A strict observance of the principles laid down in Sections 24, 29 and 30 will generally prevent cracks starting from the foundation.

The effect produced on certain soils when they become saturated with water is described in Section 9.

Next to faulty foundations, the most common cause of cracks in brick walls is probably the use of wooden lintels, as described in Section 255.

Besides the cracks that occur from these causes, cracks often occur over openings from settlement of the mortar joints in the piers or from spreading of the arches.

It is very common to see a small crack just above the end of a door or window sill, as shown in Fig. 152. Such cracks generally occur near the bottom of high walls, and are caused by the compression of the mortar in the lower joints of the pier. They may be avoided by using slip sills, as described in Section 191.

Another place where cracks produced by the settlement of mortar joints sometimes occur is where a low wall joins a very high one. To prevent such cracks the walls should be joined by a slip joint, as described in Section 206.

Generally cracks are more likely to occur in walls that are broken by frequent openings than in a plain, unbroken wall.

The use of plenty of anchors and thorough bonding will do much toward preventing cracks.

257. Damp-proof Courses.—When buildings are built on ground that is continually moist or wet the moisture is very apt to soak up into the walls from the foundations, rendering the building unhealthy and often causing the woodwork to rot. To prevent the moisture rising in this way a horizontal damp-proof course should be inserted in all walls below the level of the first floor joist. It should be at least 6 inches above the highest level of the soil touching any part of the outer walls, and should run unbroken all around them and at least 2 feet into all the cross walls; and on very wet ground, where the water is but a few feet below the surface, it should be continuous through all the walls. In buildings finished with parapet walls it is also desirable to insert a damp-proof course just above the flashing of the roof or gutter to prevent the wet from soaking down into the woodwork of the roof and into the walls below.

Materials.—These damp-proof courses may be formed of either of the following materials:

Asphalt.—A layer of rock asphalt $\frac{3}{8}$ of an inch thick makes the best damp-proof course, and should be used for all first-class buildings. The surface to receive the hot asphalt should be quite dry and should be made smooth to economize material, and all the joints should be well flushed up with mortar. The best asphalts for this purpose are the natural rock asphalt from Seyssel, Val de Travers or Ragusa, which are imported into this country in the shape of blocks and cakes. When used the cakes are melted in large kettles, mixed with a small proportion of coal tar and applied hot. One or two layers of

tarred felt imbedded in the hot asphalt may also be used with good results.

"*Roofing* slates, or even hard vitrified bricks, two courses breaking joint, laid in half cement and sand mortar, or such bricks laid without any mortar in the vertical joints, form an inexpensive damp course." Glass is also sometimes used for this purpose.

Portland Cement.—A $\frac{1}{2}$-inch layer of Portland cement mortar, mixed in the proportion of 1 part cement and 1 of sand, will often answer the purpose, but is not as desirable as the materials mentioned above.

HOLLOW WALLS.

258. Their Object.—It is well known that a solid brick wall readily absorbs moisture and transmits heat and cold. A driving rainstorm will often penetrate a 12-inch brick wall so as to dampen the wall paper or spoil the fresco decorations. It is also known that a house with damp walls is unhealthy and a frequent cause of rheumatism; besides this the moisture in the brickwork prevents the mortar, if made of lime, from becoming hard, and is also liable to communicate itself to the woodwork, thereby causing rot.

A building with damp walls will also require the consumption of very much more coal in warming than one with dry walls, as the moisture must be evaporated before the temperature of the walls can be raised.

To overcome these objections to a solid brick wall, particularly in residences and school houses, hollow or vaulted walls have been much used, and are earnestly recommended by various persons.

Theoretically, a hollow wall should prevent the passage of moisture through the wall, and by providing an air space in the wall, make the building much cooler in summer and warmer in winter.

In the actual construction of the walls, however, there are certain difficulties met with, which, to a considerable extent, offset the advantages, so that hollow walls are comparatively little used in this country.

The author believes, however, that their use might be much extended with beneficial results, especially for isolated buildings.

To obtain the full benefit of an air space it should be continuous throughout the wall, and the bond or connection between the two parts of the wall should be of such material and of such a shape that the moisture which penetrates the outer portion cannot be conveyed to the inner portion.

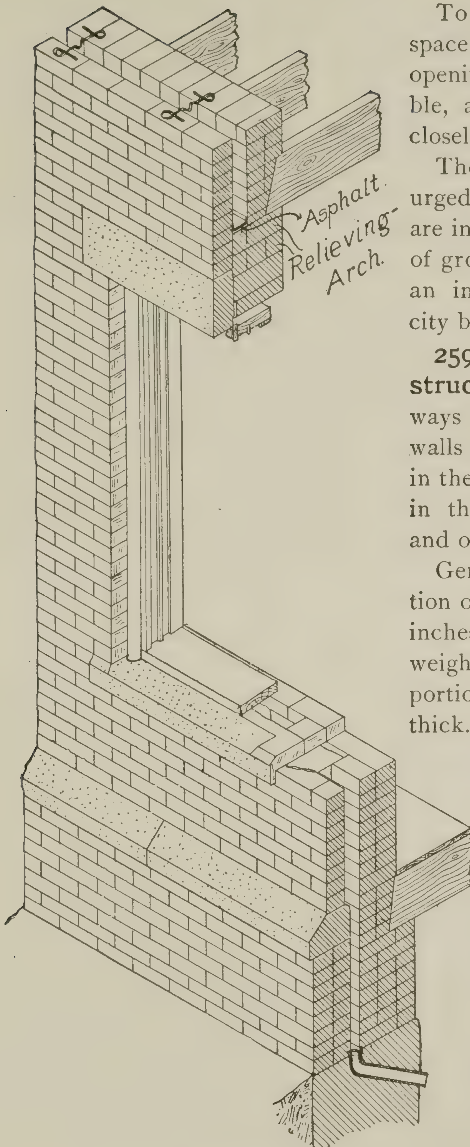


Fig. 153.

To provide a continuous air space in a wall penetrated by openings is practically impossible, although it may be quite closely approximated.

The objections commonly urged against the vaulted wall are increased cost and increase of ground area, the latter being an important consideration in city buildings.

259. Methods of Construction.—There are several ways of constructing vaulted walls; these differ principally in the method of bonding and in the thickness of the inner and outer portions of the wall.

Generally, at least one portion of the wall must be made 8 inches thick to sustain the weight of the floors, the other portion being only 4 inches thick. Probably the thicker portion of the wall is more commonly placed on the outside of the wall, but this necessitates extending the floor joist through the air space, and thus to a great extent neutralizing the benefits derived from it. By this method the thicker portion of the wall is still subjected to the injurious effects of the moisture.

For two-story buildings the author recommends that the walls be constructed as shown in Fig. 153. If the wall plate comes above the attic joist the latter

may be supported on the 4-inch wall if well built of good hard brick. If the brick are not of very good quality the 8-inch wall should be continued to the upper joist.

When the bricks, mortar and workmanship are of the best quality there is no reason why this construction should not answer for even four or five-story buildings (if used only for dwelling or lodging purposes) by making the inner portion 8 inches thick the full height and increasing the width of the air space to 6 inches.

For warehouses the bearing wall in the lower stories should be increased in thickness.

A hollow wall of a given number of bricks securely bonded is much more stable than a solid wall of the same number of bricks, and will also withstand fire better. It requires much better workmanship, however, than is generally bestowed on solid walls, and the mortar, particularly in the outer portion, must be of the best quality, and preferably of cement.

Nearly all building regulations require that at least the same quantity of brick shall be used in the construction of a hollow wall as would be used if the wall were built solid, and many of them require that both portions of the wall shall be at least 8 inches thick if the wall is used as a bearing wall.

For heavy buildings, with steel floor joist and girders, it is better to build the outer wall of the full thickness that would be required of a single wall, and to make the inner wall only 4 inches in thickness, to serve merely as a furring and to receive the plaster. Where fireproof arches are used for the floors this inner wall might without injury rest on the floor arches.

260. Bonding of Hollow Walls.—To secure proper strength in the wall it is necessary that the two portions of the wall shall be well bonded together, so that neither may buckle or get out of plumb. Until within a few years this bonding was usually accomplished by placing brick headers across the air space, with the ends slightly built into the two portions of the wall, as shown at *a*, Fig. 154.

Brick bonding, however neutralizes much of the benefit gained by the air space, as it permits of the passage of moisture through the wall wherever it is bonded. The moisture not only passes through the bond bricks, but also through the mortar droppings that invariably collect upon them.

The best method of bonding, and the only one which retains the full benefits of the air space, is by means of metal ties provided with a drip in the centre. Either of the metal ties shown in Fig. 154 may

be used. That shown at *b* is the "Morse" tie, which is made of different sizes of galvanized steel wire and from 7 to 16 inches in length. The other ties are not patented, and may be made by any blacksmith.

That shown at *e* is probably the best shape where both walls are 8 inches thick, as it gets a firm hold on the walls and is also much stiffer than the wire tie. The iron ties should either be galvanized or dipped in hot asphalt or coal tar.

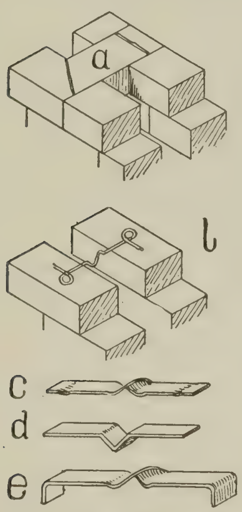


Fig. 154.

If either of the ties *b, c* or *d* are used they should be spaced every 24 inches in every *fourth* course. The tie *e*, being stronger, need be used only in every *eighth* course.

261. Construction Around Openings.—Wherever door or window openings occur in hollow walls it is necessary to build the wall solid for 8 inches at each side of the opening, and also to carry the relieving arch entirely through the wall. It is almost impossible to prevent some moisture passing through the wall at these points, but much may be done by covering the top of the relieving arch with hot tar and laying the connecting brickwork in cement mortar. The top of the relieving arch is obviously the most vulnerable point, and should be protected in some way and kept as free as possible from mortar droppings.

Ventilation of Air Space.—There seems to be some difference of opinion as to whether or not the air space should be connected with the outer air. American writers, however, appear to be generally of the opinion that the air space should be ventilated to carry off the moisture that collects on the inside of the outer portion of the wall.

It is recommended that the bottom of the air space be ventilated through openings into the cellar, and that openings be left in the inner portion of the wall just under the coping of a parapet wall, or above the attic floor joist if the wall is covered by the roof. If the air space cannot be ventilated into the attic, then ventilation flues should be carried up and topped out like a chimney, or built in connection with a chimney. It is also recommended that a U-shaped drain tile

be laid at the bottom of the air space to collect any moisture that may run down the outer wall.

262. Hollow Walls with Brick Withes.—Brick walls are sometimes built with a 4-inch inner and outer fácing connected with *solid* brick withes, as shown in Fig. 155, the air space being made 4, 8 or 12 inches, according to the height and character of the building. Congress Hall, Saratoga, N. Y., a portion of which is seven stories high, is built in the manner shown in Fig. 155, and has stood

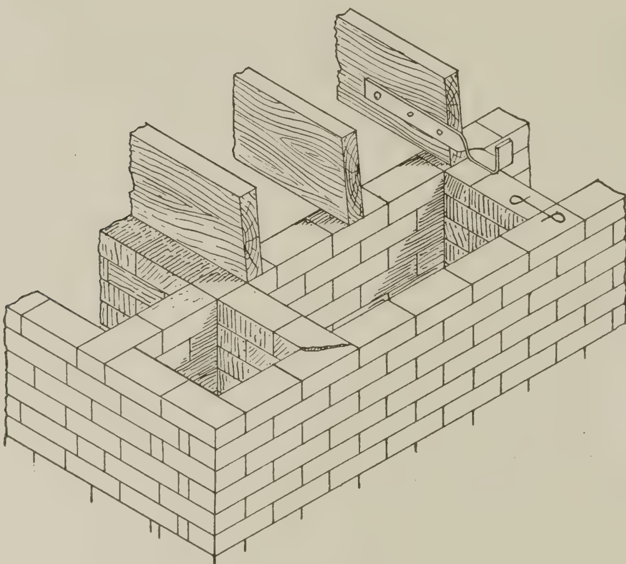


Fig. 155.

successfully. If such a wall is built of the quality of brick generally made in the New England States, and with *perfect* workmanship, it should have ample strength for any ordinary three or four-story building, and would certainly be more stable and conduct less heat and moisture from and into the building than a solid wall of one-half more bricks. With such bricks and workmanship as are commonly found in many portions of the country, however, walls built in this way should never be used for any building larger than a two-story dwelling. Theoretically, the inside of the wall opposite the withes would be subject to dampness, but, of course, not to as great an extent as with the solid wall.

For two-story dwellings, this wall, if well constructed and the withes securely bonded to the facings, should make a much more healthy and comfortable building than the solid wall.

263. Furring Blocks.—For office buildings furring blocks designed for that especial purpose are often used for lining or furring the external walls, and sometimes hollow bricks are used for the inner 4 inches of a solid wall, but the latter have not proved a success in excluding moisture. The objection to any kind of furring and to hollow brick is that there must necessarily be some connection between the *material* of the lining or furring and the wall, and this connection allows of the passage of heat and moisture.

264. Brick Veneer Construction.—It is quite common in many sections of the country to build dwellings, and even three and

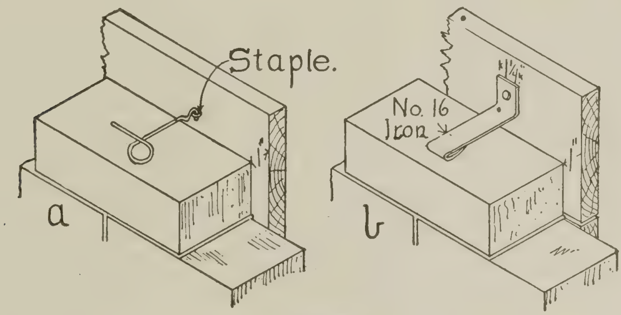


Fig. 156.

four-story buildings, with the outer walls of frame construction and then to veneer the frame with a 4-inch facing of brick. Buildings built in this way have the same appearance, both externally and internally, as if the walls were entirely of brick.

Where lumber is cheap and brickwork comparatively expensive this method of construction possesses some advantages, although it is not generally approved by architects, and should only be used where a hollow brick wall cannot be afforded. The advantages possessed by a brick-veneered frame wall over a solid brick wall are that it costs less and the air spaces prevent any possibility of the passage of moisture, and also makes the house much warmer in winter and cooler in summer.

About the only advantage that it possesses over a well-built frame building is that it reduces the insurance rate, as the veneer offers some protection from fire in adjoining buildings. A veneered build-

ing, however, is not near as safe from fire as a brick building, and would probably be destroyed by fire on the inside about as rapidly as though the frame were covered with siding or shingles.

The only differences in the planning of a veneered building from that of a frame building are that the walls are 5 inches thicker, the foundations must project sufficiently beyond the frame to support the veneer, and the elevations are drawn the same as for a brick building.

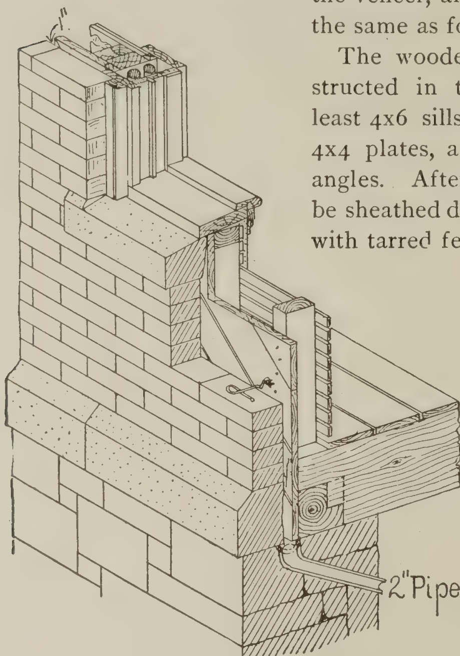


Fig. 157.

The wooden frame should be constructed in the best manner, with at least 4x6 sills, 4x8 posts, 4x6 girts and 4x4 plates, and be well braced at the angles. After the frame is up it should be sheathed diagonally and then covered with tarred felt.

It is also very important that the framing timber shall be as dry as possible, particularly the sill and girts, and the frame must be perfectly plumb and straight.

The veneer is usually laid with pressed or face brick, with plumb bond, which should be tied to the wooden wall with metal ties. The Morse tie, shown at *a*, Fig. 156, is probably the best for this purpose, although the author has used the tie shown at *b* with very satisfactory results. The ties should be placed on every other brick in every fifth course.

In laying out the wall on the floor plans 6 inches should be allowed from the outside of the studding to the face of the wall. This gives an air space of about 1 inch between the brick and sheathing and avoids chipping the bricks where the wooden wall is a little full. It is a good idea to build a 2-inch U-shaped drain tile in the foundation wall under the air space to collect any moisture that may penetrate the veneer. The air space should also be ventilated at the bottom through 2-inch drain tile, as shown in Fig. 157.

The top of the brickwork generally terminates under the eaves or gable finish. If the building has a flat roof, with parapet walls, the latter should be coped with either copper or galvanized iron and tinned on the back down to the flashing.

Fig. 157 shows a partial section through the foundation and a portion of the first story wall of a veneered dwelling to illustrate the construction described above.

DETAILS OF CONSTRUCTION IN BRICKWORK.

265. Brick Arches.—Brick arches are generally used for spanning the openings in brick walls, and where there is sufficient height for the arch they form the most durable support for the wall above. The arches should be laid with great care with full joints, and all

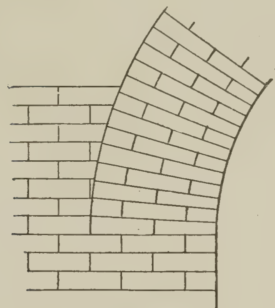


Fig. 158.

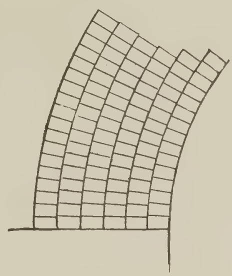


Fig. 159.

arches having a span of over 10 feet should be laid in strong cement mortar, and it is much safer to lay all brick arches in cement.

Gauged Arches.—When arches are built of common brick the bricks are laid close together on the inner edge, with wedge-shaped joints, as shown in Fig. 161, but when built of face bricks the arch rim is laid out on a floor and each brick is cut and rubbed to fit exactly the place chosen for it, so that the radial joints are of the same thickness throughout. Such work is called *gauged* work.

Bond.—The only point requiring especial mention in connection with brick arches is the bond. When gauged arches are used the bricks are generally bonded on the face of the arch to correspond with the face of the wall, as shown in Fig. 158. Such an arch is called a *bonded arch.* Bonded gauged work makes the neatest and strongest job, but it is too expensive for common brick arches.

Arches of common brick are generally built in concentric rings, either without connection with each other, except by the tenacity of

the mortar, or else bonded every few feet with bonding courses built in at intervals like voussoirs, as shown by the heavy lines at *A*, Fig. 160. When the concentric rings are all headers, as in Fig. 159, the arch is designated as a *rowlock* arch, or bond, and when built with bonding courses, as in Fig. 160, it is known as *block in course* bond. Segmental arches are often built with concentric rings of stretchers (Fig. 161), which may be bonded at right angles to the face by hoop iron. When the radius is over 15 feet this should be stronger than the rowlock bond.

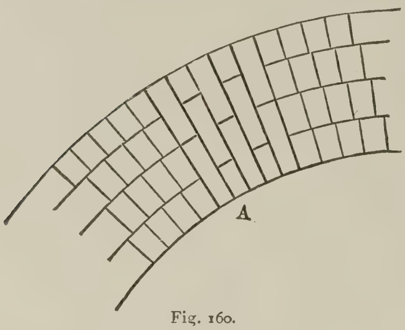


Fig. 160.

Common brick arches are sometimes bonded by introducing headers so as to unite two half brick rings wherever the joints of two such rings happen to coincide. Fig. 162 shows the bonding employed in arching the Vosburg tunnel on the Lehigh Valley Railroad, the span being 28 feet. Building an arch in concentric rings has the objection that each ring acts nearly or quite independent of the other, and the least settlement in the outer rings throws the entire pressure on the inner ring, which may not be able to resist it. When bonding courses are used, however, they serve to tie the rings together and to distribute the pressure between them, so that the above objection is overcome. For arches of wide span, or when heavily loaded, some form of block in course bond should be used. Hoop iron is often built into arch rings parallel to the soffit, and is also often worked in the radial joints to unite the different rings. The stability of an arch may be greatly increased by its use.

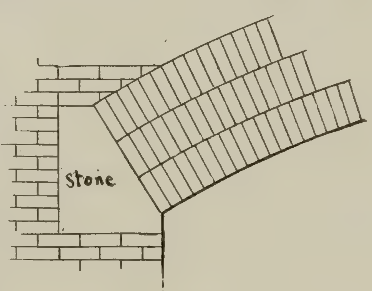


Fig. 161.

Skewback.—In building brick arches of large span it is important to have a solid bearing for the arch to spring from. Such a bearing may be best obtained by using a stone skewback, as shown in Figs. 161 and 162. The stone should be cut so as to bond into the brickwork of the pier, and the springing surface should be cut to

a true plane, radiating to the centre from which the arch is struck. For large arches the skewbacks should be bedded in cement.

Flat Arches.—Flat arches are often built over door or window openings in external walls for architectural effect. Such arches, if built with a perfectly level soffit, almost always settle a little, and it is better to give a slight curve to the soffit, as in Fig. 163, or else support the soffit of the arch on an angle bar, the vertical flange of the bar being concealed behind the arch.

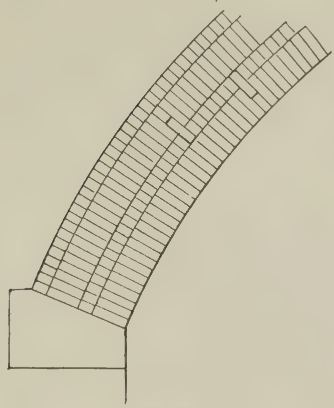


Fig. 162.

Relieving Arches.—The portion of a wall back of the face brick arch, or stone lintel over door or window openings, should be supported by a rough brick arch, as shown in Fig. 164. A wooden lintel is first put across the opening, and on this a brick core or centre is built for turning the arch. Sometimes arched wooden lintels are used and the arch turned on them. When the walls are plastered without furring the method shown in the figure is the best, as there will be less woodwork. The lintel should not have a bearing on the wall of more than 4 inches, and the arch should spring from beyond the end of the lintel as at *A*, and *not* as at *B*, as in the latter method the arch is affected by the shrinkage of the lintel.

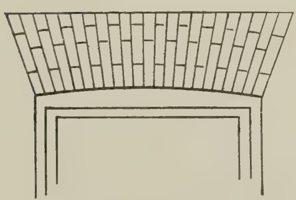


Fig. 163.

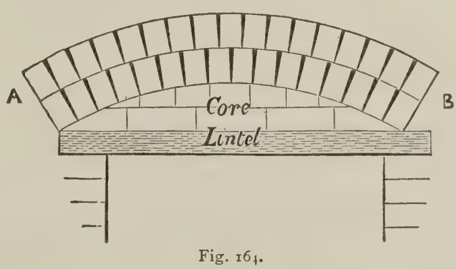


Fig. 164.

266. Vaults.—Brick vaults are usually constructed in the same way as common brick arches, except that the bricks should be bonded lengthwise of the vault.

Cross, or groined vaults, are generally supported at the intersections by diagonal arches of the proper curvature, built so as to drop 8 or 12 inches below the soffit of the vault.

Vaults may be economically constructed by a combination of brickwork and concrete, or even entirely of concrete. When built entirely of concrete, however, very strong centres are required.

Fig. 165 * shows a method of constructing vaults much used by the ancient Romans. A light temporary centre of wood was first put in place, and on this light brick arches were built to form a framework for supporting the weight of the vault until set. These

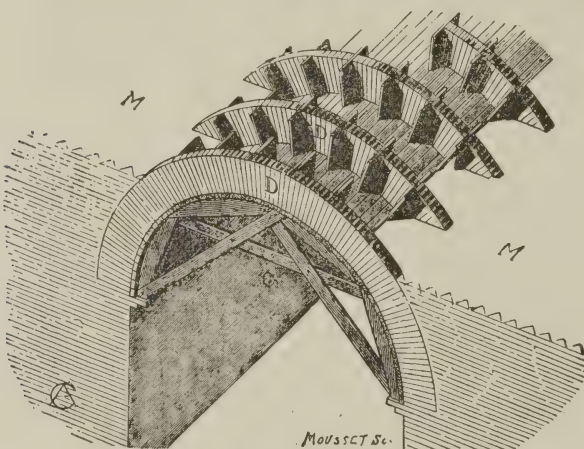


Fig. 165.

brick arches were called *armatures*, and as they became the real support of the vault only very light wooden centres were required. After the armatures were built the spaces between them were filled with rough masonry or concrete, as shown in Fig. 166.

267. Chimneys.—In planning brick chimneys the principal points to be considered are the number, arrangement and size of the flues and the height of the chimney. Every fireplace should have a separate flue extending to the top of the chimney. Two or three stoves, however, may be connected with one flue if it is of sufficient size, and the kitchen range may be connected with the furnace flue without bad results, and often the draught of the furnace will be benefited thereby. For ordinary stoves and for a small furnace an 8x8

* Figs. 165 and 166 are taken from the *Brickbuilder*, by permission.

flue is sufficiently large if plastered smooth on the inside, but it is generally better to make the furnace flues 8x12 inches and also the fireplace flues, except for very small grates.

The best smoke flue is one built of brick and lined with fire clay tile, or else a galvanized iron pipe supported in the middle of a large brick flue. When the latter arrangement is used the space surrounding the smoke pipe may be used for ventilating the adjoining rooms by simply putting registers in the wall of the flue.

When galvanized iron smoke pipes are used the metal should be at least of No. 20 gauge, and No. 16 gauge for boiler flues. Even then

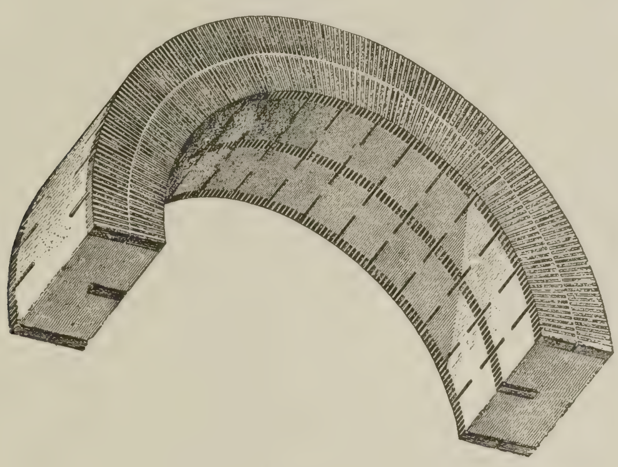


Fig. 166.

the pipe is liable to be eaten away by rust or acids within ten or twelve years. Fire clay flue lining, on the other hand, is imperishable.

Smoke flues are sometimes made only 4 inches wide. Such flues may work satisfactorily at first, but they soon get clogged with soot and fail to draw well, and should never be used unless it is impracticable to make the width greater.

More flues smoke or draw poorly on account of the chimney not being of sufficient height than from any other cause. A chimney should always extend a little above the highest point of the building or those adjacent to it, as otherwise eddies may be formed by the wind which may cause a downward draught in the flue and make it smoke. If it is impracticable to carry the chimney above the highest point of the roof it should be topped out with a hood,

open on two sides, the sides parallel to the roof being closed. The walls and *withes* (or partitions) of a chimney should be built with great care, and the joints carefully filled with mortar and the flues plastered smooth on the inside with Portland cement, both to prevent sparks or air from passing through the walls and to increase the draught. Chimneys were formerly plastered with a mixture of cowdung and lime mortar, which was called *pargetting*, but this mixture is now seldom, if ever, used. Portland cement is not affected by heat and is the best material for this purpose.

In building the chimney more or less mortar and pieces of brick are sure to drop into the flue, and a hole should be left at the bottom, with a board stuck in on a slant, to catch the falling mortar. After the chimney is topped out the board and mortar should be removed and the hole bricked up. If there are bends in the flue, openings should be left in the wall at those points for cleaning out any bricks and mortar that may lodge there. The outer wall of a chimney should be 8 inches thick, unless a flue lining is used, to prevent the smoke being chilled too rapidly.

During the construction of the building the architect or superintendent should be careful to see that no woodwork is placed within 1 inch of the walls of a flue, and that all the flues are smoothly plastered their entire height.

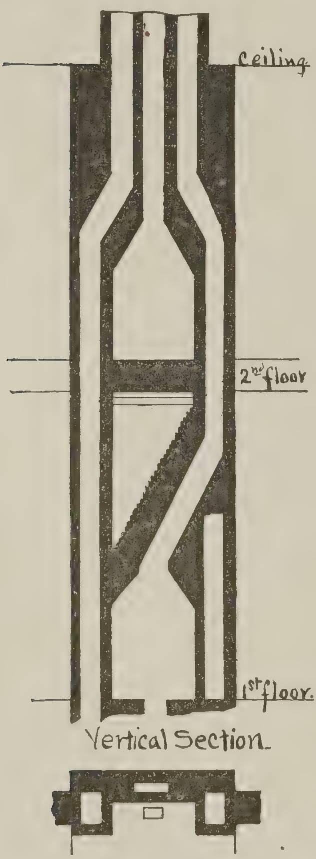
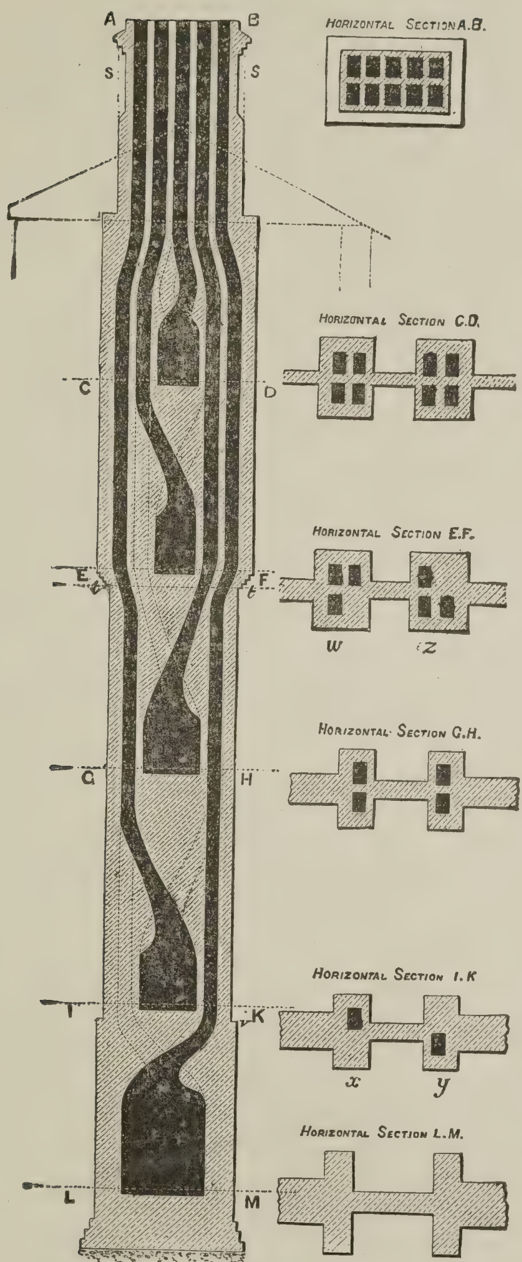


Fig. 167.—Plan.

The arrangement of the flues is ordinarily very simple. Fig. 167 shows the ordinary arrangement of the flues in a chimney containing a furnace flue and fireplaces in first and second stories, and ash flue for second story fireplace.

Fig. 168, from Part II. of "Notes on Building Construction," shows the arrangement of the flues in a double chimney, with fireplaces in five stories.


A
B
S
S
HORIZONTAL SECTION A.B.
HORIZONTAL SECTION C.D.
C
D
HORIZONTAL SECTION E.F.
E
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t
t
w
z
HORIZONTAL SECTION G.H.
G
H
HORIZONTAL SECTION I.K
I
K
x
y
HORIZONTAL SECTION L.M.
L
M

Fig 168.

268. Fireplaces.—*Rough Opening.*—In building fireplaces, no matter how they are to be finished, it is customary first to build a rough opening in the chimney from 6 to 8 inches wider than the intended width of the finished opening, and an inch or two higher, drawing in the brick above to form the flue, as shown in Figs. 167 and 168. The front wall of the chimney over the opening may be supported by a segment arch when there is sufficient abutment, but when the side walls are but 4 or 8 inches thick, heavy iron bars should be used to support the brickwork. The depth of the rough opening should be at least 12 inches, to permit of an 8-inch flue.

The bottom of the chimney, when there are fireplaces, is usually built hollow to form a receptacle for the ashes from the grate, as shown in Fig. 169. If the fireplace is to be used frequently an ash pit is almost a necessity, especially in residences, and should always be provided when practicable. When the fireplace is above the ground floor a flue can generally be built to connect the bottom of the fireplace with the ash pit. In the chimney shown by Figs. 167 and 169 the ash flue is built back of the lower fireplace. When there is no furnace flue the ash flue can be carried down at one side of the lower fireplace, thereby saving 4 inches in the thickness of the chimney. One ash flue will answer for several fireplaces. A cast iron door and frame (usually about 10x12 inches) should be built in the bottom of the ash pit to permit of removing the ashes.

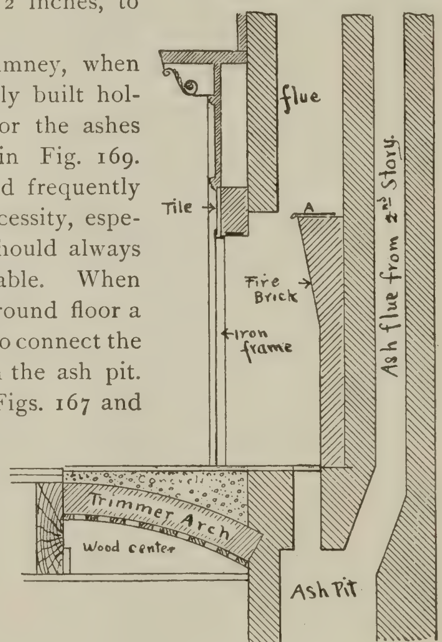


Fig. 169.

The ash pit, rough opening and flues form the chimney, and are all built at the same time by the brick mason, who also builds the trimmer arch.

Trimmer Arch.—In buildings with wooden floor construction the hearth is usually supported by a "trimmer arch," commonly 2 feet wide by the width of the chimney, turned on a wooden centre from

the chimney to the header or trimmer, as shown in Fig. 169. The centre is put up by the carpenter, one side being supported by the trimmer and the other by a projecting course on the chimney, or by flat irons driven into the joints. Although not needed for support after the arch has set, the centre is generally left in place to afford a nailing for the lath or furring strips on the ceiling below.

Sometimes a flagstone is hung from the joists to support the hearth, but a stone generally costs more than the arch, and in the opinion of the author is not as good, as the arch will adjust itself to a slight settlement in the chimney, and is not affected by shrinkage of the floor joists.

Finished Fireplace.—After the building is plastered the finished fireplace is built, usually by the parties furnishing the material, unless it is of brick, when the work may be done by any skilled brick mason.

At the present time the larger number of fireplaces are probably built with fire brick linings and tile facings and hearths, with wooden

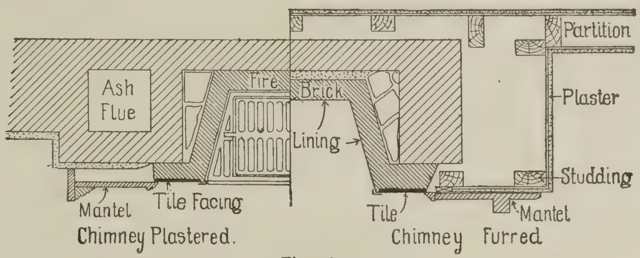


Fig 169*a*.

mantels, after the manner shown by Figs. 169 and 169*a*. The various steps in building such a fireplace are to first level up for the hearth with brick or concrete, after which the hearth and "under fire" are laid, the metal frame at the edge of the opening set up and the lining and the backing for the tile facing built. After this work is completed the tile facing is set, and when the mortar has dried out, the mantel, if of wood, is set against it. It is best to use glazed tile for the hearth and facings, and they should always be set in rich Portland cement mortar. The sides of the lining or fire box should be beveled about 3 inches to the foot, and the back should be brought inward at the top, as shown, so that the opening into the flue will be only about 3 inches wide. This opening is called the "throat," and its proportions determine in a great measure whether the draught will be good or bad.

A damper should always be provided for closing the throat. The simplest arrangement is a piece of heavy sheet iron with a ring on the edge, as shown at *A*, Fig. 169, which may be operated by the poker. A much better device, and one now quite frequently used, consists of a cast iron frame with a door which may be pushed back to give the full opening, and the door also has a sliding damper sufficient to let off the gases after the fire is well started. This device can be obtained of most mantel dealers, and generally insures a good draught. A small cast iron ash dump should also be placed in the bottom of the fireplace when there is an ash pit.

Grates.—There are a great many styles of grates that may be used in fireplaces. In a fireplace such as has been described, the "club house" grate is probably most frequently used in localities where soft coal is burned. It consists of a cast iron grate supported by four legs, and with an ornamental front about 6 inches high. It has no back or sides, but should fit close to the fire brick lining. There is also a movable front to close the opening beneath the grate. Such a grate works very well for soft coal or coke.

For fireplaces that are to be frequently or steadily used a narrow opening (say 21 inches) is most desirable, as the wider openings are very wasteful of coal.

Fireplaces in which wood is to be burned may have openings up to 4 feet wide, 3-foot openings being quite common. Wood is generally burned on andirons.

For burning hard coal, especially in ornamental fireplaces, basket grates having an open front and solid back and ends are often used. They are made of various sizes and may be used in any fireplace.

One of the most practical devices for a fireplace is the portable fireplace, which is a complete cast iron fireplace with fire box, dampers, shaking grate and separate front piece for summer. It can be set in any opening of suitable size, and is sure to draw well if the flue is reasonably large and high. These fireplaces are finished with an ornamental frame about 3 inches wide, in different finishes, and can be used with either tile, marble or brick facings. They are made with 20 and 24-inch openings.

Brick Fireplaces.—Fireplaces may be built with pressed brick facings, with either square or arched openings, and a wood mantel set against them, the same as with a tile facing. If wood is to be burned pressed brick may also be used for the linings, but they will not withstand the intense heat of a coal fire. For a coal fire fire brick should be used for the linings.

Although brick facings in connection with wooden mantels have been much used, the practice does not seem to be very desirable, either from a practical or decorative standpoint. If brick is to be used at all, it seems more desirable to make the whole mantel of brick or of brick and terra cotta. In fact there are no materials which can be used for finishing about a fireplace with better effect than brick or

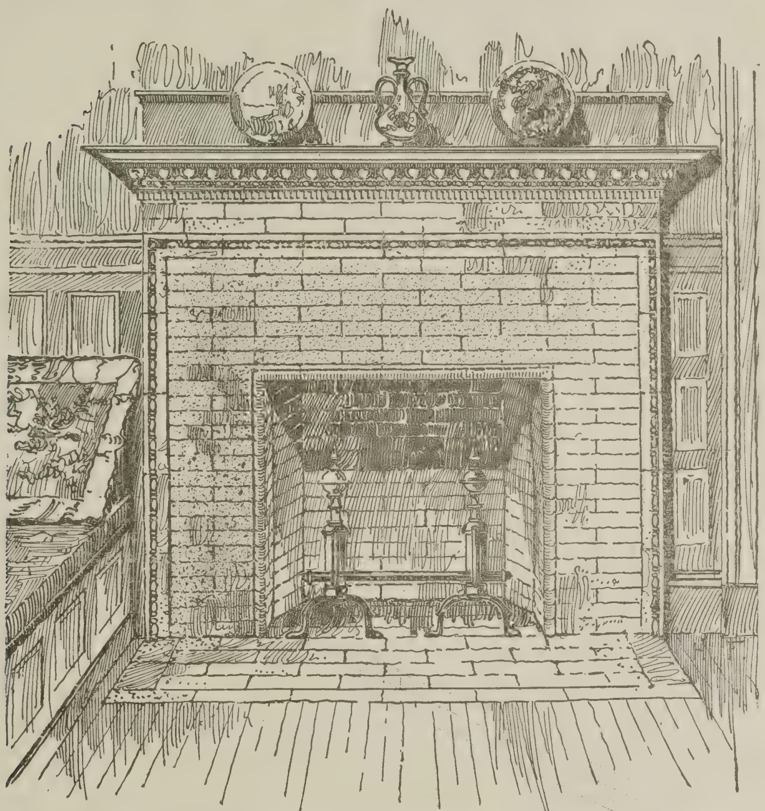


Fig. 169*b*.—Brick and Terra Cotta Fireplace Mantel. Manufactured by Fiske, Homes & Co. J. H. Ritchie, Designer.

terra cotta, although they require artistic skill in the selection of the color and in their arrangement.

The great drawback in building brick mantels in the past has been the difficulty of obtaining bricks of suitable color and accuracy, and which can be adapted to a satisfactory decorative treatment. This difficulty, however, no longer exists, as there are now two or three

firms that make a specialty of producing brick mantels of a high grade of artistic value. These mantels are designed by skilled architects to produce the highest architectural effect, and all the parts

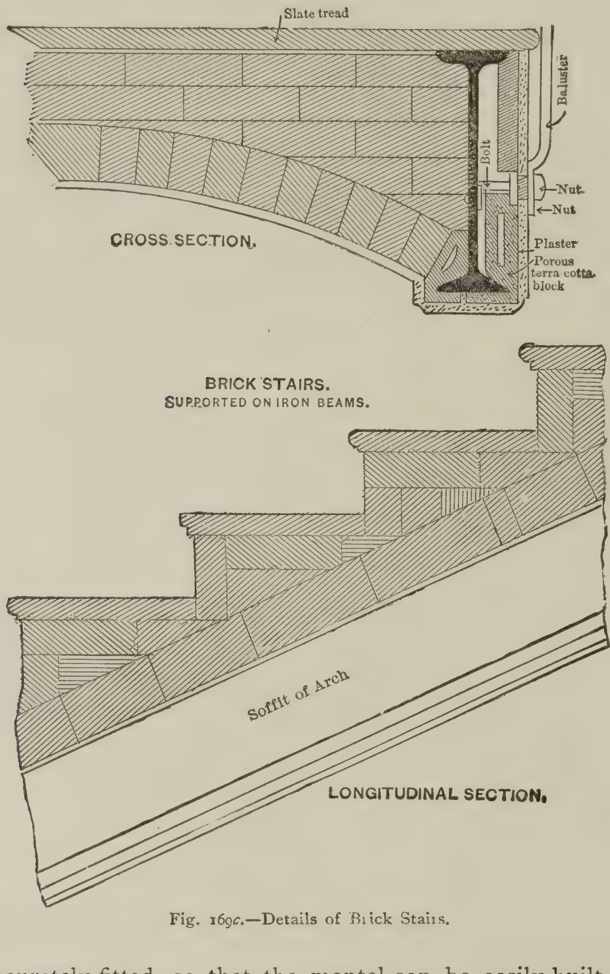


Fig. 169c.—Details of Brick Stairs.

are accurately fitted, so that the mantel can be easily built by any pressed brick mason. They are made in a variety of designs and colors, and can be varied within certain limits of size to fit a particular space. The mantels of the Philadelphia and Boston Face Brick Co. have been extensively used during the past eight years, and with very satisfactory results.

Messrs. Fiske, Homes & Co., of Boston, have also recently undertaken the production of brick and terra cotta mantels of a very high degree of excellence.

In these mantels the ornamentation is largely in terra cotta instead of moulded bricks, and a special feature of this terra cotta ornamentation is that the pieces are made in standard sizes which are interchangeable. This feature will probably be appreciated and utilized by architects, as it affords them the opportunity of making designs to suit their own individual tastes as regards the choice and arrangement of ornamentation, by bringing together in any desired combination the standard interchangeable pieces, thus gaining practically all the desirable features of special designs, with the additional advantages of moderate cost and certainty of delivery.

Staircase, House of Tristran the Hermit, Tours, France.

Fig. 169*b* illustrates a low-cost design in which the facing is made of 8x1½-inch bricks with beaded jambs, with a bead and reel border, and the cornice of egg and dart and dentil design; a wood shelf and backboard are used to give a smooth and finished effect.

268½. Brick Stairs.—For building fireproof stairs there is probably no better material than brick, unless it be Portland cement concrete in combination with metal tension bars. Brick stairs may easily be built between two brick walls by springing a segment arch from wall to wall to form the soffit and building the steps on top of this arch; or, if one side of the stairs must be open, that side may be supported by a steel I-beam, as shown in Fig. 169*c*, which should be protected by fireproof tiling. The stairs in the Pension Building at Washington were constructed in this way. The treads of the steps may be of hard pressed brick, or slate treads may be laid on top of the brick. Iron treads are not desirable, as they become slippery.

Brick Spiral Stairs.—Fig. 169*d* shows a method of constructing spiral stairs of brickwork commonly employed in Ma-

dras, India. These stairs are built without any centring, and cost in Madras less than one-third as much as iron stairs. It would seem as though this construction might be advantageously employed in this country where spiral stairs are to be built in fireproof buildings. The dimensions of a typical Madras spiral stair are about as follows:

Diameter of stair, wall to wall, inside...............	6 feet.
Diameter of newel in centre.......................	1 foot.
Headway, from top of step to arching overhead,....	7 feet $1\frac{1}{2}$ inches.
Risers, each	6 "
Tread at wall......................................	1 foot $2\frac{1}{8}$ "
Tread at newel.....................................	$2\frac{3}{8}$ "

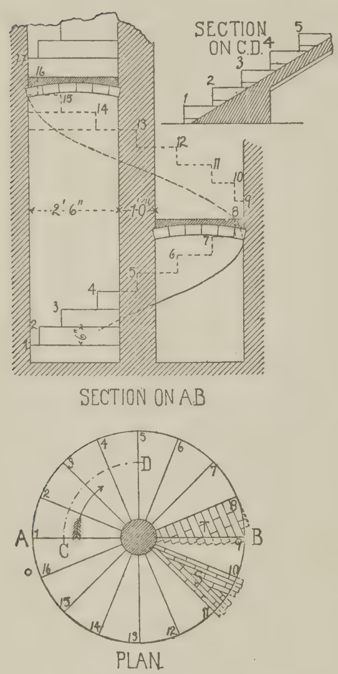


Fig. 169*d*.

Having determined the rise and number of steps in the usual way, work is commenced by building up solid two or three steps, when the arch is then started by ordinary terrace bricks, 5x3x1 inch, in lime mortar ($1\frac{1}{2}$ parts slaked lime to 1 of clean river sand). The bricks are put edgewise flat against one another, with their lengths in radii from the centre of the stair, and are simply stuck to one another by the aid of the mortar without any centring. These arch bricks are arranged as shown at *S*, the soffit being a continuous incline, as shown in the section *C D*. A slight rise, about $1\frac{1}{2}$ inch, is given to the arch as shown in the section.

For forming the steps over this arching ordinary bricks are used, usually 9x$4\frac{1}{2}$x3 inches, trimmed to position and placed on edge as at *T* in the plan.

After a reasonable time for the mortar to harden the work should bear a load of 300 pounds placed on a step and show no sign of giving. With good materials the steps will bear much heavier loads.—*J. M.*, *in Indian Engineering.*

269. Brick Nogging.—*Nogging* is a term that is applied to brickwork filled in between the studding of wooden partitions. It is often employed in wooden partitions of dwellings and tenement houses to obstruct the passage of fire, sound and vermin. As no particular weight comes upon the brick, and they are not exposed to moisture, the cheapest kind of brick may be used for this purpose.

The brick should be laid in mortar, as in a 4-inch wall. If the partition is to be lathed with wooden laths it is necessary that the width of the bricks shall not be quite equal to that of the studding, to allow for a *clinch* to the plaster. When $3\frac{3}{4}$-inch studding is used it will be necessary either to clip the brick or lay them on edge.

When the studding of a partition rests on the cap of the partition below it is an excellent idea to fill in the space between the floor and the ceiling below with nogging to prevent the passage of fire and mice, and two courses of brick laid on horizontal bridging is also a good means of preventing fire or vermin ascending in a partition.

270. Cleaning Down.—Soon after the walls are completed all pressed or face brick should be washed and scrubbed with muriatic acid and water, using either a scrubbing brush or corn broom. The scrubbing should be continued until all stains are removed. At the same time all open joints under window sills and the joints in the stone and terra cotta work should be pointed, so that when the cleaning down is completed the entire wall will be in perfect condition.

271. Efflorescence.—After a heavy driving storm of rain or damp snow the face of many brick buildings will often be seen to be covered with a sort of white efflorescence, which greatly mars the appearance of the brickwork. This efflorescence is due either to soda in the bricks, which is drawn out by capillary attraction to the surface, where it dries out, leaving a white deposit, or to pyrites in the clay, which when burned gives rise to sulphuric acid, which unites with the magnesia in the lime mortar. In either case the efflorescence only appears after the bricks have been thoroughly saturated with moisture, either when laid or by a driving storm, perhaps several years after. According to Mr. Samuel Cabot it is never due to the bricks alone, and seldom to the lime alone. It seems to be impossible to prevent its occurrence except by protecting the bricks by some waterproof or oily solution. After the white appears on the surface it may be washed off with clear water by vigorous scrubbing, and if, after the brickwork has become dry, a good coat of boiled linseed oil is applied, it will prevent the reappearance of the white until the life of the oil is destroyed, usually from three to five years, when another coat may be applied. Any other preparation which renders the bricks impervious to moisture will prevent the efflorescence.

272. Damp-proofing.*—All brick and stone walls absorb more or less moisture, and a wall 12 inches thick may sometimes be soaked through in a driving rainstorm. In the dry climates of Colorado, Arizona and New Mexico such storms rarely occur, and it is customary

* See also page 403.

in those localities to plaster directly on the inside of the walls. In nearly all other portions of the country, however, it is desirable, for the sake of health and economy in heating, if not absolutely necessary, either to furr or strip the inside of solid walls with 1x2-inch strips, or to render the walls damp-proof, either by a coating of some kind applied to the outside of the wall, or by building the wall hollow. Furring the wall with wooden strips and then lathing on them prevents the moisture from coming through the plastering, but it does not prevent the wall itself from becoming soaked, thereby necessitating more heat to warm the building and gradually tending to the destruction of the wall. The hollow wall is probably the best device, when properly built, for preventing the passage of moisture and also of heat, but in most cases it is also the most expensive.

Brickwork may be rendered impervious to moisture either by painting the outside of the walls with white lead and oil or by coating the wall with a preparation of paraffine, or by some of the patented waterproofing processes. The preparations containing paraffine are usually applied hot, and the wall is also heated previous to the application by a portable heater. They give fairly good results, but are quite expensive, owing to the time and labor required for their application.

Sylvester's process, which consists in covering the surface of the wall with two washes or solutions—one composed of Castile soap and water and one of alum and water—has been used with much success for this purpose. A full description of the successful application of this process to the walls of the gate houses of the Croton Reservoir in Central Park, New York, is given in Baker's *Treatise on Masonry Construction*, pp. 178-180.

All of these preparations change somewhat the color and grain of the brick, and are generally considered as detracting from the appearance of the building.

Boiled linseed oil is often applied to brick walls, and two coats will prevent the absorption of moisture for from one to three years. The oil does not greatly change the color of the brick, and generally improves the appearance of a wall which has become stained or discolored in any way.

Common white lead and oil paint is probably the best material for damp-proofing external walls above ground, but it entirely changes the appearance of the building. Painting of new work should be deferred until the wall has been finished at least three months, and three coats should be given at first, after which one coat applied

every four or five years will answer. A preparation known as *Duresco* and made in England has been used in New York and Chicago for damp-proofing with very satisfactory results. In Chicago it was used for coating the *inside* of the walls before the plastering was applied to prevent the moisture penetrating the plastering, which purpose it seems to have successfully accomplished.

Duresco, when applied to common or soft brick, not only renders them weatherproof, but the color gives the permanent appearance for which pressed brick are valued. It dries with a hard, uniform, impervious surface free from gloss, and does not flake off or change color. It is put up in 56-pound kegs, that quantity being sufficient for covering 1,000 square feet, two coats.

Cabot's Brick Preservative (made in Boston, Mass.).—It is claimed by the manufacturer that this preparation forms a thorough waterproofing for brickwork and sandstone, thus preventing the white efflorescence, the disintegration of chimneys by frost, and the growth of fungus.

It does not change the natural texture of the material to which it is applied and leaves no gloss. It has been found by actual experiment that one coat of this preservative makes as good a waterproofing as three coats of boiled linseed oil.

The preservative is manufactured in two forms: colorless, for use on any kind of brick to render them waterproof and to prevent the efflorescence, and, with red color added, to bring the bricks to an even shade without destroying the texture.

This material is applied with a brush in the same way as oil, no heat being necessary. To get the best effect the brickwork should first be washed down with acid (preferably nitric acid) to remove any efflorescence already formed. One gallon will cover about 200 square feet on the average rough brick and a little more on pressed brick. One coat is generally sufficient unless the bricks are extremely soft and porous.

To prevent moisture penetrating the top of brick vaults built underground a coating of asphalt, from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch thick and applied at a temperature of from 360° to 518° F., seems to give the best results. Common coal tar pitch is often used for the purpose, but is not as good as asphalt. If the vault is to be covered with soil for vegetation the top course of brick should be laid in hot asphalt in addition to the coating.

273. Crushing Strength of Brickwork.—In the majority of brick and stone buildings the crushing strength of brickwork need

be considered only in connection with piers, arches and under bearing plates or templates. The strength of brickwork varies with the strength of the individual bricks, the quality and composition of the mortar, the workmanship and bond, and also with the age of the brickwork. It is not the purpose here to enter minutely into the subject of the strength of materials, but for general practice the following safe loads may be allowed for the crushing strength of brickwork in the cases above mentioned: For New England hard-burned brick, in lime mortar, 8 to 10 tons per square foot (112 to 138 pounds per square inch).

Same brick laid in mortar composed of Rosendale cement 1 part, sand 2 parts, 12 tons per square foot (166 pounds per square inch).

Same brick in cement and lime mortar, 1 to 3, 14 tons per square foot (194 pounds per square inch).

Same brick in Portland cement and sand mortar, 1 to 2, 15 tons per square foot (200 pounds per square inch).

Average hard-burned Western brick, in Louisville cement mortar, 1 to 2, 10 tons per square foot.

Same brick in Portland cement mortar, 1 to 2, 12½ tons per square foot (175 pounds per square inch).

It should always be remembered that the strength of brick piers depends largely upon the thoroughness with which they are bonded, and the building of all piers should be carefully watched by the superintendent.

274. Measurement of Brickwork.—Brickwork is generally measured by the one thousand bricks laid in the wall. The usual custom of brick masons is to take the *outside* superficial area of the wall (so that the corners are measured twice) and multiply by 15 for an 8 or 9-inch wall, 22½ for a 12 or 13-inch wall and 30 for a 16 or 18-inch wall, the result being in bricks. These figures give about the actual number of bricks required to build the wall in the Eastern States, but in the Western States, where the bricks are larger, they give about one-third more than the actual number of bricks contained in the wall, and the price is regulated accordingly. During the author's experience, in both the Eastern and Western States, he has never known any deviation from these figures by brick masons. In the West two kinds of measurement are known, *kiln count* being used to designate the actual number of bricks purchased and used, and *wall measure*, the number of bricks there would be on the basis of 22½ bricks to 1 superficial foot of 12-inch wall.

In regard to deducting for the openings, custom varies in different localities, but unless the openings are unusually large no deduction is generally made for common brickwork. For measuring face brick the superficial area of the wall is taken, with the openings omitted, but if the reveals of the windows are more than 4 inches they are added to the wall area. The number of brick to the superficial foot depends upon the size of the brick used, seven and one-half being the average number.

Hollow walls are often measured the same as solid walls of the same thickness. Chimneys with 8x8 or 8x12 flues are generally measured as solid.

Where stone trimmings, such as caps, sills, quoins and occasional belt courses are used, if the brick mason sets the stone no deduction is usually made for face brick, but if it is set by another contractor an allowance is sometimes made for the face brick displaced by the stone.

As custom varies considerably in the measurement of brickwork, when the work is done by measurement the contract should distinctly state how the work is to be measured and if deductions are to be made for the openings and stonework. Some builders reduce all the brickwork to cubic feet and estimate the cost in that way for common brickwork.

275. Superintendence of Brickwork.—The various portions of the work that require especial superintendence have been mentioned in describing the manner of doing the work. In general the points in which brickwork is most commonly slighted are in wetting and laying the brick. The importance of wetting the brick is fully set forth in Section 238. In the laying of the brick it is often difficult to get the mason to use sufficient mortar to thoroughly fill all the joints and to shove the bricks. The quality of the mortar should also be frequently examined, as brick masons in some localities like to mix a little loam with the sand to make the mortar "work well."

The bonding of the walls should be watched to see that the bond courses are used as often as specified. The bonding of piers should be particularly looked after. The laying of the face brick and ornamental features requires more skill, but is not so apt to be slighted as the back of the wall.

The superintendent should also see that the dimensions of the building are properly followed, openings left in their proper places, and the courses kept level and the wall plumb.

In very high stories, particularly in halls and churches, the walls should be stayed with temporary braces until the permanent timbers can be built in. It is also important to see that all bearing plates are well bedded, and that all floor anchors, etc., are securely built in; also to see that all recesses for pipes, etc., marked on the plans are left in the proper places, and that all smoke and vent flues are smoothly plastered.

Chapter VIII.

ARCHITECTURAL TERRA COTTA.

270. Composition and Manufacture.—Terra cotta is composed of practically the same material as bricks, and its characteristics, as far as the material is concerned, are the same. Terra cotta, however, requires for its successful production a much better quality of clay than is generally used for bricks, while the process of manufacture is entirely different.

The first consideration in the manufacture of terra cotta is the selection of the material. No one locality gives all the clay required for first-class material, and each shade and tint of terra cotta requires the mingling of certain clays from different localities to regulate the color.

A great variety of excellent clays are mined in Northern and Central New Jersey, large quantities being marketed annually for making terra cotta, as well as for fire bricks, pottery, tiles, etc. The color varies from light cream to a dark red.

A partial vitrification of the mass is also desirable in the production of terra cotta, as it enhances the durability of the body. To achieve this, different materials are added which tend to fuse the body to a harder consistency. The vitrifying ingredients usually added to the terra cotta clays are pure white sand, old pottery and fire bricks finely pulverized, and clay previously burned, termed "grog."

The clay after being mined must be properly seasoned before being delivered at the factory. After being received the clay is crushed and ground, or washed, then mixed with grit, "grog" and water. The clay is then piled in layers, each quality being in a separate layer or stratum. As many as ten or twelve strata or layers are piled together, and from this mass perpendicular cuts are taken, and the whole is again thoroughly tempered in a pug mill, or between rollers.

After passing through the machinery, which thoroughly mixes all the ingredients, the plastic mass is moulded into small cakes for convenience in handling and sent up to the moulding rooms.

If several pieces of terra cotta of the same size and shape are required, a full size model of plaster and clay is first made, and from

this a plaster mould is taken. In the making of these models and moulds the highest grade of skilled labor is required. When the moulds are dry they are sent to the pressing department ; here the plastic clay is pressed into the moulds by hand, and when partially dry the work is turned out on the floor. The ware is then ready for the carver or modeler, if it is decorative work that requires the use of their tools, or for the clay finisher if it only requires undercutting or some special work to make it fit in with other work.

The work is then carefully dried on the drying floor, when it is ready to be put into the kilns, where it must remain seven days for burning and cooling before it is ready for use. The kilns commonly used for burning terra cotta are of the beehive, down-draft pattern. In burning terra cotta the alkaline salts contained in the clays yield an efflorescence, which, acting upon the silicates of the surface, vitrify to a greater degree the exterior of the terra cotta, and this harder face should remain intact and under no avoidable circumstances be allowed to be chipped, chiseled or broken, although the joints sometimes require chiseling or trimming to ensure a close fit.

If only a single piece of terra cotta is to be made, or where no repetition is intended, no moulds are used, the clay being modeled directly into the required shape. The finished product thus bears directly the impress of the modeling artist. It can be studied, improved or modified, and, when entirely satisfactory, burnt. On this account terra cotta possesses, for highly decorative work, an advantage over all other building materials.

Terra cotta is usually made in blocks about 18 inches long, 6 to 12 inches deep and of a height determined by the character of the work. To save material and prevent warping the blocks are formed of an outer shell, connected and braced by partitions about 1 inch thick. The partitions should be arranged so that the spaces shall not exceed 6 inches, and should have numerous holes in them to form a clinch for the mortar and brickwork used for filling.

277. Color.—The color of terra cotta ranges from white to a deep red, according to the chemical constituents of the clays used.

Within the past ten years a great impetus has been given to the production of special colors in architectural clay products. In 1885 fully four-fifths of the terra cotta produced in the United States was red ; now hardly one-fifth is of that color. Buffs and grays of several shades, white and cream-white and the richer and warmer colors of the fire-flashed old gold and mottled are now the prevailing colors.

By the use of chemicals almost any required tone or color may be obtained. As a rule, however, it is safer, and a better quality of material is likely to be obtained, by using only those colors which are natural to the clay. A color which necessitates underburning or overburning of the clay should not be used.

If any particular color, not natural to the material, is desired the architect should consult with the manufacturer in regard to its effect upon the durability and quality of the finished product.

278. **Use.**—The modern employments for terra cotta, architecturally, are for tiles, panels and medallions; pilasters, columns, capitals and bases; sills, jambs, mullions and lintels; skewbacks or springers, arches and keys; spandrels, pediments and tympanums; mouldings, belt courses, friezes and cornices; coping, chimney tops, cresting, finials and terminals.

Terra cotta is also employed for brackets, consoles, gargoyles, corbels, oriel and tracery windows, and for interior use for altars, baptismal fonts, balusters, newels, pedestals, statues, niches, mantels, fireplace facings, and in fireproof buildings for base mouldings and base panels, and also in plain blocks for ashlar.

Terra cotta is also suitable for all kinds of garden decorations, such as balustrades, ferndelabras, flower baskets and vases and other horticultural appliances.

279. **Durability.**—The principal value of terra cotta lies in its durability. When made of the right material and properly burned it is impervious to wet, or nearly so, and hence is not subject to the disintegrating action of frost, which is a powerful agent in the destruction of stone; neither does it vegetate, as is the case with many stones. The ordinary acid gases contained in the atmosphere of cities have no effect upon it, and the dust which gathers on the mouldings, etc., is washed away by every rainfall. Underburned terra cotta does not possess these qualities in so great a degree, as it is more or less absorbent. Another great advantage possessed by terra cotta is its resistance to heat, which makes it the most desirable material for the trimmings and ornamental work in the walls of fireproof buildings. Although terra cotta has been used in this country for but a comparatively short time, it has thus far proved very satisfactory, and the characteristics above indicated would point to its being, in common with the better qualities of brick, the most durable of all building materials.

In Europe there are numerous examples of architectural terra cotta which have been exposed to the weather for three or four

centuries and are still in good condition, while stonework subjected to the same conditions is more or less worn and decayed.

280. Inspection.—A sharp metallic, bell-like ring and a clean, close fracture are good proof of homogeneousness, compactness and strength. Precision of the forms is in the highest degree essential, and can result only from homogeneous material and a thorough and experienced knowledge of firing.

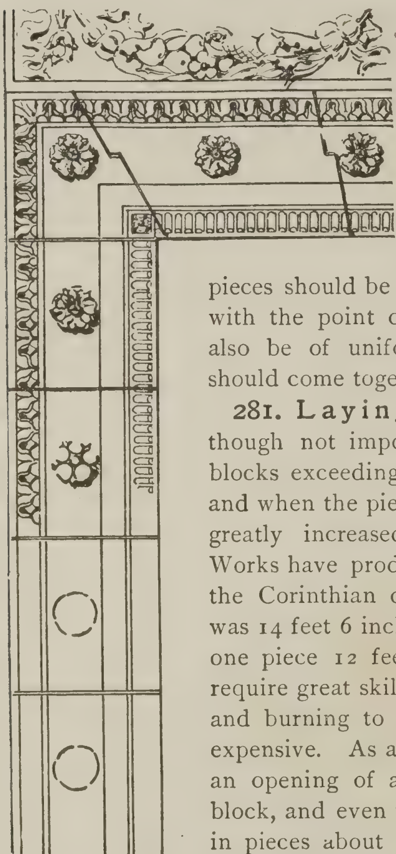


Fig. 170.

No spalled, chipped, glazed. or warped pieces of terra cotta should be accepted, and the pieces should be so hard as to resist scratching with the point of a knife. The blocks should also be of uniform color, and all mouldings should come together perfectly at the joints.

281. Laying Out.—It is impracticable, though not impossible, to make terra cotta in blocks exceeding 3 feet by 4 feet by 18 inches, and when the pieces exceed this size the cost is greatly increased. The Boston Terra Cotta Works have produced a column and capital of the Corinthian order, in white terra cotta, that was 14 feet 6 inches in height, the shaft being in one piece 12 feet long; but such large pieces require great skill and care in the manufacture and burning to prevent warping, and are very expensive. As a rule it is impracticable to span an opening of any considerable length in one block, and even window sills are generally made in pieces about 18 inches long. Jamb blocks should not exceed 1 foot in height or thereabouts. Mullions, transoms and tracery should be made in as many pieces as the design will admit, and if there are several members in the depths of the mouldings they should be as much divided as possible, care being taken that each alternate course bonds well upon the other. The strings and cornices should be divided into as short lengths (18 inches to 2 feet) as convenient.

The architect should show the jointing of the terra cotta on his drawings, the joints being arranged to conform with the above

requirements, and the work should also be designed so as to form a part of the construction and to adapt itself as far as possible to being divided into small pieces. When used for trimmings in connection

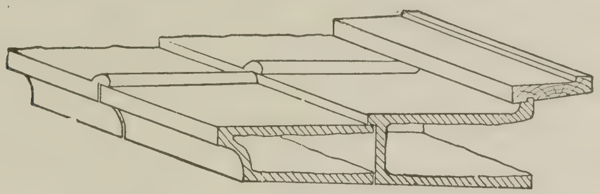


Fig. 171.

with brickwork it is very essential that the pieces shall be of the exact height to bond in with the courses of brick, and a small piece of brickwork should be built up, to get the exact heights, before the final drawings for terra cotta are sent to the manufacturers. All horizontal joints should be proportioned so as to be equal to about one-fourth the height of the joints in the adjoining face brickwork. For elaborate work it is generally necessary to consult with the manufacturers in regard to the best disposition of the joints.

282. Examples of Construction.—As an example of the jointing of jambs and lintels, Fig. 170, which is from the Volta Building, Messrs. Peabody & Stearns, architects, is given.

Window sills, when made of several pieces, should have roll joints as shown in Fig. 171, which should terminate *under* the wood sills rather than against the edge.

Cornices.—Where buildings are trimmed with terra cotta the cornice is generally made of the same material. For cornices having considerable projection terra cotta possesses the advantages over stone of being much lighter, thus permitting of lighter walls, and in most cases much cheaper. With stone cornices it is necessary that the various pieces be of sufficient depth to balance on the wall. With terra cotta cornices, however, this is not customary, the various pieces

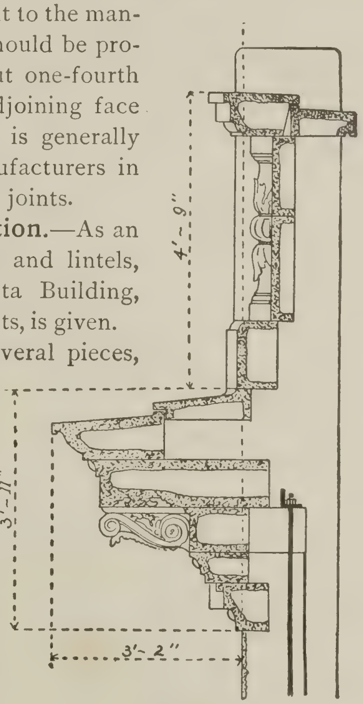


Fig. 172.

being made to build into the wall only from 8 to 12 inches and being supported by ironwork. When modillions are used they may generally be made to support the construction, as shown in Figs. 172 and 173.

Generally small steel I or T-beams are used for supporting the projecting members, and where the projection is so great as to overbalance the weight of the masonry on the built-in end, allowing for the weight of snow on the projection, the inner end of the beam must be anchored down by rods, carried down into the wall until the weight of the masonry above the anchor is ample to counteract the leverage of the projection. Unless the wall is very heavy it is also advisable to anchor the top of the wall to the roof timbers to prevent its inclining outward.

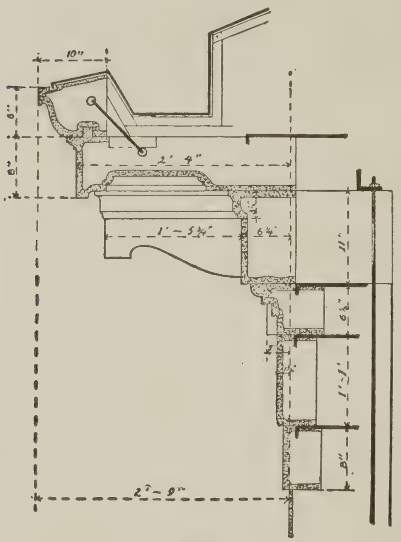


Fig. 173.

Figs. 172 and 173 * show sections of terra cotta cornices that have actually been erected and the manner in which they are supported.

Fig. 174 shows a section of the cornice on the Equitable Life Insurance Co.'s Building, in Denver, Col.

These sections may be taken as models of good and economical construction in terra cotta where a heavy projection is required.

When a cornice is to be supported by ironwork the method of anchoring must be decided on before the work is made, as provision must be made in making the blocks for inserting the beams or anchors. Generally the beams are placed in the joints in a slot made for the purpose. A copy of the detail drawings should be furnished the contractor for the ironwork, to enable him to get out his part of the work correctly. For other examples, see Section 287½.

283. Setting and Pointing.—*Setting.*—Terra cotta should always be set in either the natural (such as Rosendale or Utica) cements, or in Portland cement, mixed with sand, in about the same

* From the *Clay Worker*, by permission.

way as stone is set. As soon as set the outside of the joints should be raked out to a depth of $\frac{3}{4}$ of an inch to allow for pointing and to prevent chipping. The terra cotta should be built up in advance of the backing, one course at a time, and all the voids should be *filled*

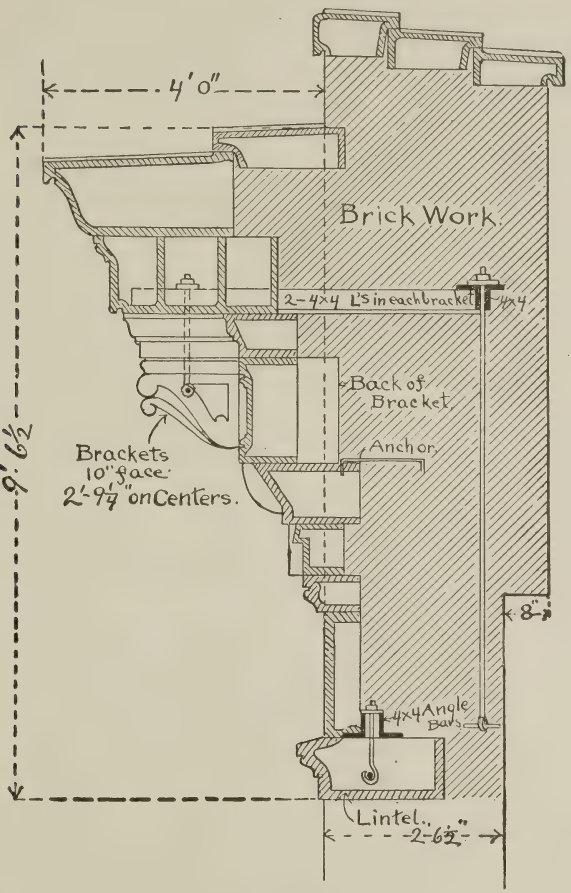


Fig. 174.

with mortar, into which bricks should be forced to make the work as solid as possible. All blocks not solidly built into the walls should be anchored with galvanized iron clamps, the same as described for stonework, and, as a rule, all projecting members over 6 inches in height should be anchored in this way.

Terra cotta work is generally set by the brick mason, but the specifications should distinctly state who is to do the setting and pointing.

Pointing.—After the walls are up the joints should be pointed with Portland cement colored with a mineral pigment to correspond with the color of the terra cotta. The pointing is done in the same way as described for stone, except that the horizontal joints in all sills, and washes of belt courses and cornices, unless covered with a roll. should be raked out about 2 inches deep and caulked with oakum for about 1 inch and then filled with an elastic cement

284. **Time.**—One of the principal objections to the use of terra cotta is the time required to obtain it, especially when the building is some distance from the manufactory. Some six weeks are required for the production of terra cotta of the ordinary kind, and the architect should see that all the drawings for the terra cotta work are completed and delivered to the maker at as early a stage in the work as possible, so that he may have ample time to produce it.

Small pieces of terra cotta may sometimes be obtained within two weeks from the receipt of the order when the moulds are already on hand. It is always more expensive, however, to attempt to turn out work in such short order, and inexpedient on account of the risks in forcing the drying.

285. **Cost.**—A single piece of terra cotta, or plain caps and sills, costs about the same as freestone, when the rough stone can be delivered at a price not exceeding ninety cents per cubic foot. When a number of pieces exactly alike are required, however, it can be produced in terra cotta cheaper than in stone, unless the terra cotta has to be transported at a large cost for freight. The advantage in point of cost in favor of terra cotta is greatly increased if there is a large proportion of moulded work, and especially if the mouldings are enriched, or if there are a number of ornamental panels, carved capitals, etc. It should always be remembered that if economy is desired it can best be obtained by a repetition of the ornamental features, so as to require as few different models as possible. When stock patterns can be used the cost is also considerably less than when the work has to be made from special designs.

The use of terra cotta for trimmings, and especially for heavy cornices, in place of stone, often reduces the cost of the walls and foundations, as the weight of the terra cotta will be much less than that of stone, and the walls and foundations may be made lighter in consequence.

286. Weight and Strength.—The weight of terra cotta in *solid blocks* averages 122 pounds per cubic foot. When made in hollow blocks 1½ inches thick the weight varies from 65 to 85 pounds per cubic foot, the smaller pieces weighing the most. For pieces 12x18 inches or larger on the face, 70 pounds per cubic foot should be a fair average.

The crushing strength of terra cotta blocks in 2-inch cubes varies from 5,000 to 7,000 pounds per square inch.

Hollow blocks of terra cotta, unfilled, have sustained 186 tons per square foot on blocks 1 foot high.

From these and other tests the author would place the safe working strength of terra cotta blocks in the wall at 5 tons per square foot when *unfilled* and 10 tons per square foot when *filled solid* with brickwork or concrete.

If it is desired to test the strength of special pieces, two or three small pieces should be broken from the blocks and ground to 1-inch cubes, and then tested in a machine. Should the average results fall much below 6,000 pounds the material should be rejected.

Transverse Strength of Modillions.—A cornice modillion measuring 11½ inches high and 8 inches wide at the wall line, with a projection of 2 feet, carried a load of 4,083 pounds without injury. A similar modillion 5½ inches high, 6 inches wide, with a projection of 14 inches, broke under 2,650 pounds. Another bracket from the same mould, inserted in the same hole, sustained 2,400 pounds without breaking.

287. Protection.—The carpenter's specifications should provide for boxing all moulded and ornamental work with rough pine boards to guard against damage during construction. Hemlock is unsuited for this purpose, as it is liable to stain the terra cotta.

287½. Other Examples of Terra Cotta Construction.—Many excellent illustrations of terra cotta construction have been contributed to the *Brickbuilder* during the past two years (1897–98), by Mr. Thomas Cusack, which are accompanied by a great amount of practical information and advice regarding the subjects treated.

Through the courtesy of Mr. Cusack and the publishers, we are enabled to reprint two illustrations, Figs. 174*a* and *b*, showing the best construction of a balcony and of parapet balustrading.

Fig. 174*a* illustrates the design of a conventional balcony, such as might be projected from a second or third story window by way of embellishment. The manner in which it *was* constructed is shown by the section below the elevation. The objections to this construc-

tion, briefly stated, are: 1. "The cantilevers have a strength out of all proportion to the load that could by any possibility be put upon them." 2. "They are placed about 7 inches too high, cutting through the top bed of the modillions and into the bottom of the platform, thereby causing an incurable weakness in both." 3. "The

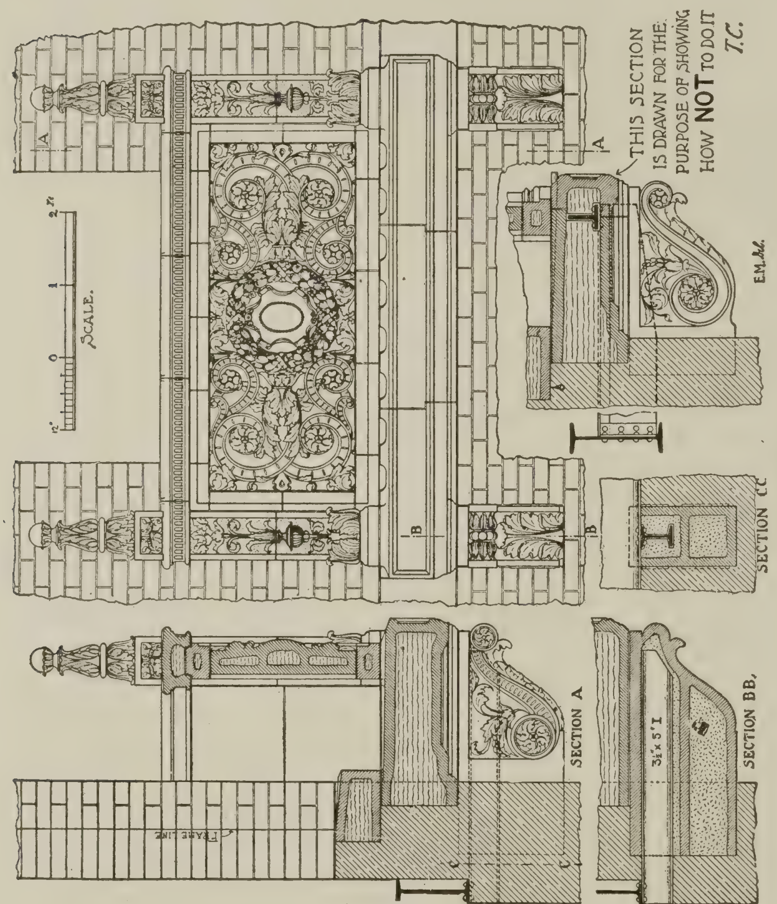


Fig. 174*a*.

inverted tee resting upon them is not only quite unnecessary, but positively suicidal, so far as the terra cotta is concerned." A plan, such as is shown in sections *AA*, *BB*, and *CC*, would have been much simpler, less expensive and avoided the objections above noted.

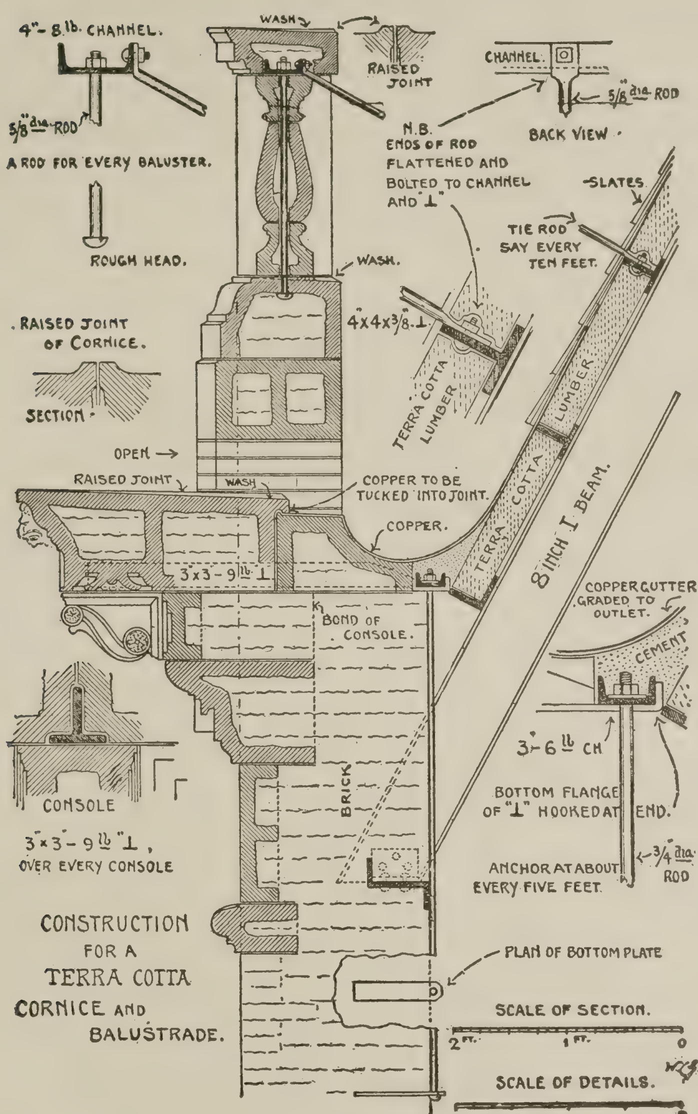

4"- 8 lb. CHANNEL.
5/8" dia. ROD
A ROD FOR EVERY BALUSTER.
ROUGH HEAD.
WASH
RAISED JOINT
CHANNEL.
5/8" dia. ROD
BACK VIEW
N.B.
ENDS OF ROD FLATTENED AND BOLTED TO CHANNEL AND "⊥"
SLATES
TIE ROD SAY EVERY TEN FEET.
WASH.
RAISED JOINT OF CORNICE.
SECTION
4"x4x3/8 ⊥
TERRA COTTA LUMBER
TERRA COTTA LUMBER
OPEN
RAISED JOINT
WASH
COPPER TO BE TUCKED INTO JOINT.
COPPER.
8 INCH I BEAM.
3x3-9 lb ⊥
COPPER GUTTER GRADED TO OUTLET.
CEMENT
BOND OF CONSOLE.
3"-6 lb CH
BRICK
CONSOLE
BOTTOM FLANGE OF "⊥" HOOKED AT END.
3"x3"-9 lb "⊥, OVER EVERY CONSOLE
ANCHOR AT ABOUT EVERY FIVE FEET.
3/4 dia. ROD
CONSTRUCTION FOR A TERRA COTTA CORNICE AND BALUSTRADE.
PLAN OF BOTTOM PLATE
SCALE OF SECTION.
2 FT. 1 FT. 0
SCALE OF DETAILS.

Fig. 174b.

"The modillion in this case would be made with four walls and one horizontal partition, forming two open chambers as at *CC*. Into the upper one of these we would insert a $3\frac{1}{2}$ by 5-inch I-beam, the end of which would be attached to floor beam, and the surrounding space filled with concrete, as at *BB*. In this way we would get the full strength of the cantilever cased in cement, without weakening the modillions by needlessly cutting through its outer shell. The platform would be made in three complete blocks of moderate size, two of them resting directly on the brackets, the centre block joggle-jointed on two sides with a third side built into the wall."

A balcony constructed in this way would have a strength many times in excess of any weight ever likely to be placed upon it.

Fig. 174*b* shows the construction of the terra cotta cornice and parapet of a residence at Madison Avenue and Thirty-ninth Street, New York, which may be taken as the typical construction of such work.

The balusters are made in three pieces, for the reasons that balusters made in one piece are subject to cleaving where the halves are united, and are very liable to twist in the kiln, besides being more expensive in the first instance with no compensating advantages. If the cornice were much broken by piers or angles, the diagonal stays to roof might be omitted.

Chapter IX.

FIREPROOFING

288. Most of the materials employed for protecting the structural portions of buildings from fire and heat, and for filling between the floor beams and rafters, are of earthy composition and come within the province of the mason or plasterer.

The *constructive* fireproof materials—*i. e.*, those which have to support any weight—most extensively used in this country are: dense, hollow tiles, porous terra cotta tiles or blocks and various concrete compositions, generally combined with steel in the shape of small bars, wires or netting. These materials are used in different shapes and in different ways, both of which are, as a rule, covered by patents controlled by large manufacturing corporations. Most of these manufacturing corporations also take contracts to furnish all the fireproofing material required in the building and to put it in place, leaving the building ready for the plasterer and carpenter. A few manufacturers, however, prefer to confine their business to manufacturing the material, and of late years the practice has become quite general, especially in the East, for the owner or general contractor to buy tiles and the mason contractor on the job to build them in place in the building.

While with contractors of large experience this practice has worked very well, it will generally be found more satisfactory to the architect to have the party that furnishes the material put it in place, as the responsibility for the proper and prompt execution of the work is then undivided. If the putting in place of the fireproofing must be done by another party, the contract should be let to some one who is familiar with that kind of work and with the material to be employed.

Whichever way the contract is to be let, however, it is well for the architect to specify both the kind and quality of the material to be employed and also the way in which the work is to be done. It is also advisable and customary to require that the floor construction shall be subjected to certain tests before it is accepted.

The kind of material and method of fireproofing that is to be employed should also be decided upon before the framing plans are made, as some systems require different framing than others. Some systems also effect a sufficient saving in dead weight to enable lighter beams and columns to be used than are required where heavy arches of dense tile are used.

If competitive bids are desired to assist in determining the kind of fireproofing to be employed, these can usually be obtained before the plans are completed, the position of the columns determining the spans and width of arches.

If it is decided to use either porous or dense tile arches it is not absolutely necessary to specify any particular make of tile, but the specifications may be written so that any tile may be used which fulfills the conditions therein contained.

The subject of fireproof construction has received a great deal of attention during the past few years, and the increased demand for a safe and economical system of fireproofing has led to the introduction of many systems, nearly all of which, however, may be said to be still in the experimental state. A great many tests have been made of the strength of fireproof floors, but many of these have been conducted in such a way as to be of little value in determining the real strength of the system. As it is not the purpose of this book to enter extensively into the subject of strength of materials, but rather to describe methods of construction, we shall here undertake only to describe the methods of fireproofing most commonly in vogue in this country, referring the reader to the author's "*Pocket Book*," and especially to a record of tests on fireproof floors published in the *Brickbuilder* for 1895, for more complete data relating to their strength and to the designing of the metal work.

For lack of space it will also be necessary to confine ourself to the description of the fireproofing of buildings constructed of incombustible materials. The fireproofing of buildings constructed with wooden joist and posts is now almost entirely confined to plastering applied to some form of metal lathing, or to plaster boards or blocks These will be described in Chapter XI.

The fireproofing of non-combustible buildings may be divided into three divisions—floor construction, partitions and the casings of posts, girders, trusses, etc. For convenience we will describe the different methods under the above headings, first, however, describing briefly the different materials employed in fireproofing.

FIREPROOFING MATERIALS.

289. Various materials have been introduced at different times for the purpose of making buildings fireproof. Experience has shown, however, that the only practical method of producing a really fireproof building is by using only incombustible materials for its structural parts and protecting all structural metal work with some fire, water and heat-resisting material. The ideal fireproof building would undoubtedly be one that was constructed entirely of brickwork and terra cotta, with brick, concrete or tile floors or roofs, built in the form of vaults sprung from brick piers and without the employment of structural metal work. Such a building, if properly designed and built, would withstand the combined action of all the elements for centuries. Modern commercial requirements, however, demand that the vertical supports shall be as small and as far apart as possible, and that the floors shall be thin and have level ceilings, and these can only be obtained by the use of metal work.

The materials that have been found to successfully answer the purposes of modern fireproofing are confined to the products of clay, some concretes and lime and cement mortars under certain conditions.

290. Clay Products.—Of all fire-resisting materials burnt clay has the most numerous applications in incombustible building. For the construction of floors and partitions, and for the casing of posts and girders, the clay is moulded into hollow tiles or blocks of two general kinds.

These are known by several different names: The one by such as porous terra cotta, terra cotta lumber, cellular pottery, porous tiling, soft tiling, etc.; the other by fire clay tile, hollow pottery, hard tile, terra cotta, dense tiling, etc.* For convenience the first will be hereinafter referred to as porous tiling and the second as dense tiling. The terms "hollow tiling" and "fireproof tiling" will be used when both are referred to in a general way.

291. *Porous tiling* is formed by mixing sawdust and finely cut straw with pure clay and submitting it to an intense heat, by the action of which the sawdust is destroyed, leaving the material light and porous like pumice stone. When properly made it will not crack or break from unequal heating or from being suddenly cooled by

* The Pioneer Fireproof Construction Company have also recently introduced a new material which they call "semi-porous hollow tile." This material is considerably lighter than the dense tiles formerly made by them, and is claimed to stand the fire and water tests equally as well as porous tiling.

water when in a heated condition. It can also be cut with a saw or edge tools, and nails or screws may be easily driven into it for securing interior finish, slates, tiles, etc.

For the successful resistance of heat, and as a non-conductor, the author believes there is no building material equal to it, especially when used in thin sections. To obtain the above qualities in their fullest extent the blocks should be manufactured from tough plastic clays, with which a small percentage of fire clay should be mixed.

Porous tiles, when properly made and burned, should be compact, tough and hard, ringing when struck with metal. Poorly mixed pressed or burned tiles, or tiles from short or sandy clays, present a ragged, soft and crumbly appearance, and are not desirable.

Porous tiles for floor construction, or wherever they may have to carry considerable weight, should be made with not less than 1-inch shells, and the webs or partitions dividing the spaces should be from $\frac{3}{4}$ to $\frac{7}{8}$ inch thick, according to the size of the hollows.

Porous tiling possesses the advantages over hard tiling of being light, tough and elastic, while dense tiles are hard and brittle.

292. *Dense tiling* is made generally of fire clay, combined with potters' clay, plastic clays or tough brick clays, moulded by dies into the various hollow forms required for commercial use. The clay is subjected during its manufacture to a high pressure while in a moist or damp state, which gives the finished material great crushing strength. After drying the tiles are burned like terra cotta in a kiln.

Previous to the year 1890 dense tiling was almost exclusively used for the construction of floor arches, and even at the present day it appears to be more extensively used for this purpose than the porous tiling, the latter being confined principally to the end-method system of floor arches.

Dense tiling in solid blocks is unquestionably stronger than porous tiling, although more brittle. When made from fire clay it is undoubtedly a thoroughly fireproof and non-conducting material, but it will not stand the combined effects of fire and cold water as well as the porous tiling. In outer walls, exposed to the weather and required to be light, dense tiling is very desirable. Some manufacturers furnish it with a semi glazed surface for outer walls of buildings. For such use it has great durability and effectually stops moisture.

In using dense tiling for fireproof filling care should be taken that the tiles are free from cracks and sound and hard burnt.

293. Concretes.—Concrete made of Portland cement, mixed with sand, crushed stone, pieces of burnt fire clay, broken bricks or

tiles, has been successfully used in Europe as a fireproof material for many years, and what few tests have been made upon it appear to prove that it is a highly fire-resisting material, and it is now so considered by well-informed engineers and architects.

Professor Bauschinger, of the Munich Technical School, tested pillars of various materials by repeatedly heating them red hot and then drenching them with water. In his report he says: "Of all materials tested Portland cement concrete stood the best, and ordinary and clinker brick laid in Portland cement mortar stood almost equally as well."

Concrete construction has been largely used in California for many years on account of its fireproof qualities, and it is probable that it will be much more extensively used in the future in all portions of the country.

Plaster Concretes.—In Paris a composition of plaster of Paris and broken brick, chips, etc., has been used for generations for forming ceilings between beams, and its durability is there unquestioned. A composition consisting of 5 parts by weight of plaster of Paris and 1 part of wood shavings, mixed with sufficient water to bring the mass to the consistency of a thin paste, has been lately introduced in this country in connection with the Metropolitan system of floor construction. It is claimed that this material is so remarkable a non-conductor of heat that a moderate thickness of it prevents the passage of nearly all warmth.

"In severe fire tests the beams have remained cold, and consequently were unaffected. When exposed to flame for a long time the composition is attacked to a depth of from $\frac{3}{16}$ to $\frac{5}{8}$ of an inch, the remainder being unaffected, and when water is thrown upon it the mass does not fly or crack. When made thoroughly wet the composition is not destroyed."

This composition is much lighter in weight than ordinary cement concrete.

Lime mortar, and most, if not all, of the hard mortars or patent plasters, when applied on metal lathing, will resist almost any degree of heat, and will withstand the action of water for a long time.

FLOOR CONSTRUCTIONS.

294. The improvements in fireproof floor construction during the past fifteen years have been many and in rapid succession. Previous to 1880 so-called fireproof floors were constructed of brick arches turned between the lower flanges of wrought iron I-beams. These

arches, with the concrete used for leveling, were very heavy, and as the bottoms of the beams were unprotected and the ceiling formed by the arches was very undesirable, brick arches soon gave place to arches of hollow dense tile. The increased demand for fireproof construction, taken in conjunction with the reduction in the prices of steel and fireproofing which occurred about the year 1889, led to many improvements in the designs for hollow tile floor arches, and also to the introduction of various systems of construction based upon the use of concrete and plaster compositions, combined with steel wires, bars and cables, used in different shapes and in different ways, the chief aim of the inventors or designers being to secure the lightest and most economical floor consistent with ample strength and thorough fire protection.

In the following pages the author has endeavored to give an impartial description of the various systems at present approved by the leading architects and engineers.

295. Hollow Tile Floors.—*Flat Construction.*—There are three general schemes of flat tile construction at present in vogue in this country. The first and oldest is known as the *side method*, in which the tiles lie side by side between the beams, as shown in Figs. 175, 176 and 177. In the second scheme, known as the *end method*, the blocks run at right angles to the beams, abutting end to end, as shown in Figs. 178 and 180. The third method is a cross between the first and second, the skewback (or abutment) being made as in the side construction, and the "interiors" or keys abutting end to end between the keys, as shown in Fig. 181. This method is known by different names, such as the "Johnson Arch," "Excelsior Arch," "Combination Arch," etc.

296. Side-Method Arches.—The hollow tile floor arches first used in this country were made of dense tile, formed essentially like those shown in Fig. 175, except that no provision was made for protecting the bottom of the beams except by the plaster on the ceiling. It was soon found that the bottom of the beams must be more thoroughly protected from heat, as when unprotected they warped and twisted so badly during a fire as to destroy the building. The skewbacks were, therefore, made so as to drop from $\frac{3}{4}$ to 1 inch below the bottom of the beams, and either to extend under the beam or else to hold a thin tile dovetailed between them, as shown in the figure. Arches of this type were used for several years, but it was found that they were not strong enough to sustain severe loads

and the sudden strains caused by moving heavy safes, or to withstand the rough treatment and heavy weights that floors are subjected to while the building is in course of erection. The blocks were, therefore, strengthened by the introduction of horizontal and vertical webs, resulting in the shapes shown in Figs. 176 and 177, which represent the best types of dense tile arches with ribs parallel to beams made at the present time.

Arches similar to these are also made of porous tiling, but this

Fig. 175.

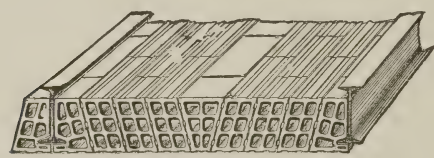


Fig. 176.

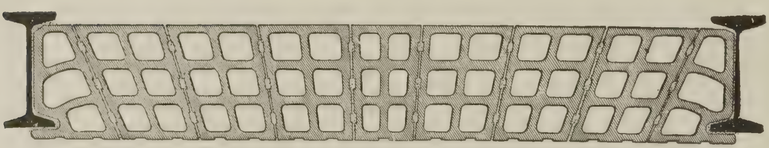


Fig. 177.

material is more generally used in the end-method types. Most of the side-method arches have beveled joints, which are parallel to the sides of the key, as shown in Fig. 176, although arches are now made with radius joints, as shown in Fig. 177. Theoretically the latter joint should make the strongest arch, but the increased cost of making so many different shapes of blocks prevents it being much used.

The blocks in the side-method arches break joint endways, so as to completely bond the arch, as shown in Fig. 176. Arches of the type shown in Figs. 176 and 177 undoubtedly have ample strength for all ordinary purposes, and the author believes there is no record

of their failure when in actual use in buildings. The few comparative tests that have been made, however, would appear to prove that *for a given weight* the side-method arch is not as strong as those built on the end method.

297. End-Method Arches.—In this method the blocks are generally made rectangular in shape, with one vertical and one horizontal partition, and with bevel end joints. In this system it is not the practice to have the blocks in one row break joint with those in another, as it entails extra expense in setting. When this is done, however, the substantialness of the floor is increased.

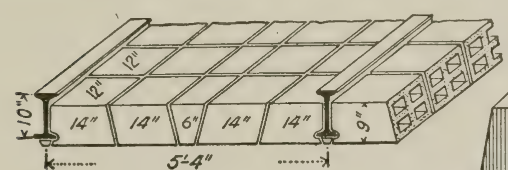


Fig. 178.

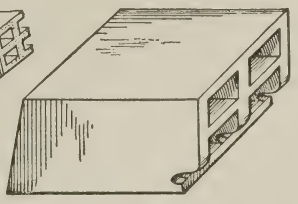


Fig. 179.

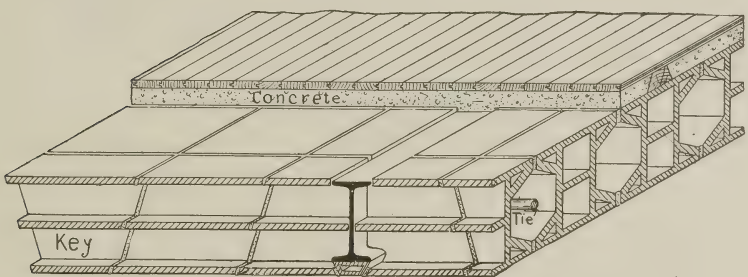


Fig. 180.

The most common type of end-method arch is that shown in Fig. 178, which was first brought into general use by Mr. Thomas A. Lee, and is often designated as the "Lee End-method Arch." It has the advantage of simplicity and economy in manufacture, as all the blocks for a given depth of arch can be made with one die. Most, if not all, manufacturers making this type of arch use porous terra cotta in its construction. These arches require very heavy webs in order to give sufficient bearing on the beams, which greatly increases the weight of the arch. Fig. 179 shows an isometric view of one of the "butment" pieces or hanches.

Some complaint has been made by architects that they find it difficult to get a strictly flat ceiling with this type of arch.

The open ends of the hollow tiles not being well adapted to receive mortar for the mortar joint, the mortar often squeezes out, permitting some of the blocks to drop below the others.

As there is no bond between the rows of tiles, if a single tile in a row should be broken or knocked out of place, the entire row will fall, and for the same reason a single tile cannot be omitted for making a temporary hole, as may be done in side-method arches.

Where the tile blocks abut endways they should be cut to fit perfectly between the beams, so that the divisions will abut perfectly against each other. Solid plates may, however, be placed between the ends of the tile blocks without injurious effect, and, in fact, the author believes that such plates would give a stronger joint.

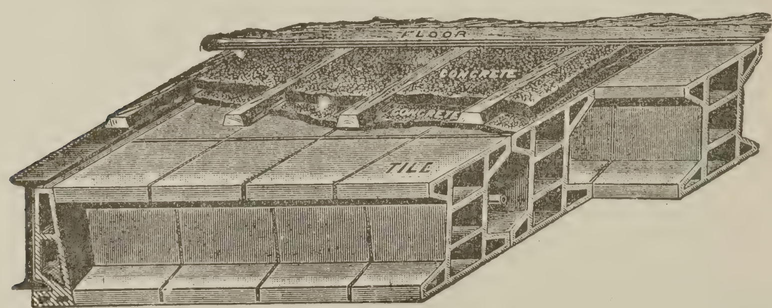


Fig. 181.

Fig. 180 represents the transverse system of floor arch construction now made by the Pioneer Company. The interiors are of the same shape as those used in their former system (Fig. 181), sometimes called the Johnson Arch, but instead of using parallel abutments end-section abutments are used, as shown in the figure. Whenever the former system was tested to destruction the abutments were almost invariably the parts which failed. It was for this reason that a different style of abutment or skewback was adopted, and the manufacturers claim that they now have the strongest and lightest flat tile arch on the market. This arch is made of dense tile, with webs and flanges $\frac{1}{2}$ and $\frac{3}{4}$ inches thick respectively.

298. Combination of Side and End Methods.—There are several styles of combination arches now manufactured. The object in making this shape of arch is to obtain the strength of the end-

method construction and at the same time get a flat bearing for the skewbacks. In order, however, to develop the full strength of the interior blocks the skewbacks should be made *very strong* and with several partitions, as they are generally the weakest portion of the arch.

Fig. 181 illustrates the "Excelsior" dense tile arch made by Henry Maurer & Son. This arch was patented by Mr. E. V. Johnson, formerly general manager of the Pioneer Company, and was formerly made also by that company. The shape of the interior blocks undoubtedly gives great strength with the minimum amount of material.

This arch has been quite extensively used in Chicago and also in Eastern cities, and apparently has given general satisfaction.

An end-method, dense tile flat arch, with side-method skewbacks, is also made by the Empire Fireproofing Company. The interior

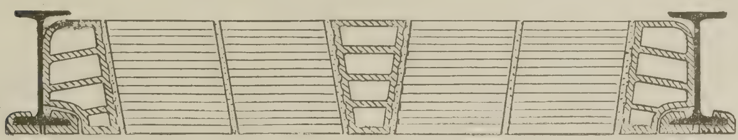


Fig. 182.

blocks have vertical and horizontal partitions similar to the Lee tile, but the sides of the tile, instead of being a true plane, have an offset at the middle of the tile, so that one course laps over the other, thereby preventing any possibility of the tiles slipping down, which sometimes occurs in the ordinary end-method arch.

Fig. 182 shows a triple web combination flat arch made by the Hocking Clay Manufacturing Company and also their patent flange cover for beams.

299. Depth, Weight and Strength of Flat Tile Arches.—Flat arches made on the side-method principle may be had in depths from 6 to 12 inches, and those made on the end method from 6 to 15 inches.

The depth of arch most frequently used for office buildings and retail stores is 10 inches, the girders being spaced so as to use 10-inch steel floor beams spaced from 5 to 6 feet apart. As a rule the depth of the arch should be about equal to the depth of the beam, as it is just about as cheap and much better construction to use deeper tiling and less concrete filling.

The following tables give the published weights and safe span for both dense and porous tiling :

TABLE X.—WEIGHTS AND SPANS FOR FLAT HOLLOW TILE ARCHES.

Depth of Arch.	Span between Beams.	Weight per sq. ft.
DENSE TILE.		
6 inches.	3 feet 6 inches to 4 feet.	22—29 pounds.
7 inches.	4 feet to 4 feet 6 inches.	27—32 pounds.
8 inches.	4 feet 6 inches to 5 feet 6 inches.	30—35 pounds.
9 inches.	5 feet to 5 feet 9 inches.	32—37 pounds.
10 inches.	5 feet 9 inches to 6 feet 6 inches.	34—41 pounds.
12 inches.	6 feet 6 inches to 7 feet 6 inches.	37—38 pounds.
POROUS TILE—END METHOD.		
6 inches.	3 feet to 5 feet.	21 pounds.
7 inches.	3 feet 6 inches to 5 feet 6 inches.	24 pounds.
8 inches.	4 feet to 6 feet.	27 pounds.
9 inches.	4 feet 6 inches to 6 feet 6 inches.	30 pounds.
10 inches.	5 feet to 7 feet.	33 pounds.
12 inches.	6 feet to 8 feet.	37 pounds.
15 inches.	7 feet 6 inches to 10 feet.	43 pounds.

The weight of the Pioneer Company's transverse arches (Fig. 180), as given by the manufacturers, is as follows :

DEPTH OF ARCH.	WEIGHT PER SQ. FT.	DEPTH OF ARCH.	WEIGHT PER SQ. FT.
8 inches.	22 pounds.	12 inches.	30 pounds.
9 inches.	24 pounds.	15 inches.	35 pounds.
10 inches.	26 pounds.	17 inches.	40 pounds.

The lighter weights in the third column for dense arches are for the "Excelsior" arch ; the heavier weights are for the arches shown in Figs. 176 and 177.

From a few tests of the weight of blocks, as they were being delivered at the building, the author is inclined to believe that the actual weights of both dense and hollow tile will generally run at least 10 per cent. over those given in manufacturers' catalogues. (See Section 312.)

The *strength* of hollow tile floors can only be determined by actual experiment.

At the tests made at Denver,* December, 1890, two 10-inch dense tile arches (5-foot span), with one horizontal web and built on the side method, failed under distributed loads of 271 and 428 pounds per

* See full account in *American Architect and Building News*, March 28, 1891.

square foot, respectively. A porous tile end-method arch, 10 inches deep, with two horizontal webs, sustained 757 pounds per square foot for two hours without breaking.

Tests made at Richmond, Va., in 1891 of 6-inch and 12-inch side-method arches made by the Empire Fireproofing Company, showed a variation of from 288 to 579 pounds per square foot for the 6-inch arches and from 554 to 1,057 pounds per square foot for the 12-inch arches, the average strength of the nine 12-inch arches being 858 pounds per square foot.

The Pioneer Company describe a test of a 15-inch flat arch similar to that shown in Fig. 181, in which the arch sustained 3,287 pounds per square foot (over an area 4x4 feet) before breaking.

The average breaking weight of five arches of 10-inch tile, with spans varying from 4 feet 11 inches to 5 feet 6 inches, tested by the Metropolitan Company, was 519 pounds per square foot.

It is generally considered by engineers that a tile arch should not fail under a load less than five times that which it is intended to carry. Arches of the types shown in Figs. 176–182, inclusive, if properly set and built of sound blocks, should be abundantly safe for office floors and light stores when proportioned according to the table. The instances where tile arches have failed when in actual use are very few indeed.

The *cost* of hollow tile arches of either kind, set in place ready for plastering in lots of 20,000 square feet, ranges from 14 cents to 25 cents per square foot, according to size and weight of the tile. In Chicago the average price is 20 cents.

300. Manner of Setting Tile Arches.—Hollow tile arches of whatever type should be set in a good Rosendale or Portland cement mortar on plank centring, slightly cambered. The best centring for flat arches is that in which the planks run at right angles to the beams and rest on 2x6 sound lumber centre pieces, placed midway between the beams and extending parallel with them. These centre pieces are supported by T-bolts from like centre pieces above, crossing the beams. The planks on which the tiles are laid should be 2-inch plank, dressed on one side to a uniform thickness and laid close together. If the soffit tile is a separate piece it should first be laid directly under the beam on the planking; if a projecting skewback is used, then the skewbacks must first be set, after which the centring is tightened by screwing down the nuts on the T-bolts until the soffit tile, or skewbacks, are hard against the beams and the planking has a crown not exceeding $\frac{1}{4}$ of an inch in spans of 6 feet.

This system gives what is very essential—a firm and steady centre on which to construct the flat tile work. The tiles should be shoved in place with close joints and keys should fit close. The centres should remain from twelve to thirty-six hours, according to condition of weather, depth of tiling and mortar used. When centres are "struck" the ceiling should be straight, even, free from open joints, crevices and cracks, ready to receive plastering.

Wherever openings are required through the floor they may be made by punching a hole through the blocks; or, if the side-method arch is used, a single block may be omitted. Small holes may afterward be plugged up with mortar and broken pieces of tile.

The variations in width of spans between beams is provided for by supplying tiles of different sizes, both for interiors and keys, whereby a variety of combinations can be secured. A great variety of skew-backs are also provided for fitting different sizes of beams.

Tie-Rods.—All forms of flat or segmental tile arches require that the beams supporting them shall be bolted together with tie-rods to take up the thrust of the arch. These tie-rods are usually $\frac{3}{4}$ inch in diameter and spaced from 5 to 7 feet apart. They should be secured to the web of the beam near the bottom flanges and drawn tightly in place by nut and thread.

301. Protection.—The laying of flat construction in winter weather without roof protection should not be practiced in climates where frequent severe rain and snow storms are followed by hard freezing and thawing, as the mortar joints are liable to be weakened or ruptured, resulting in more or less deflection of the arches. When it is intended to plaster on the under side of the arches the architect should see that the smoke and soot from the boiler used for the hoisting plant are not allowed to strike the arches, as neither can be removed, and they are sure to stain the plaster. For the same reason the architect should see that only clean water is used for mixing the mortar, and that it is not allowed to flow over the arches.

Many architects have had trouble, where flat tile arches have been used, from stains and excrescence appearing on the plastered ceiling after the latter had become dry. Such stains cannot always be concealed, even by oil paint, and the only way in which they may be avoided is by observing the above precautions and not plastering until the arches are well dried out. A coating of Duresco applied to the bottom of the arches before plastering has been recommended as a safe precaution against stains

The architect should also see that the green arches are not overloaded with building material by the other contractors.

302. Floor and Ceiling Finish.—The under side of flat tile arches is usually finished with two coats of plaster applied directly to the bottom of the tiles. If there are inequalities in the surfaces of the arches they should be filled with natural cement and sand mortar before plastering. False plaster beams may either be formed on metal furring, bolted to the under side of the arches and covered with wire lathing, or the furring may be of wood, as its consumption in case of fire would in no way endanger the building. Metal furring, however, is better, as it does not shrink.

Wooden furring strips to form nailings for wood mouldings, etc., may be secured to the soffits of the arches by punching slot holes in the bottom of the blocks and inserting T-headed bolts.

The upper surface of the arches is generally covered with concrete of a sufficient depth to allow for bedding in it the wooden strips to which the floor boards are nailed.

The general custom in regard to the size of floor strips and depth of filling is to use 2x4-inch well-seasoned wood strips, beveled to 2 inches wide on top and laid at right angles to the beams and 16 inches apart from centres. The concrete is first leveled to the tops of the highest beams and the strips then laid in place by the carpenter. The mason then fills between the strips to within $\frac{1}{8}$ inch of their top with concrete, pressed down hard against the strips. A single matched flooring is then nailed to the wood strips. In New York 3x4-inch strips are often used, the strips being notched down over the beams 1 inch. The strips, also, do not always run at right angles to the beams, although the general opinion appears to be that they should do so wherever practicable.

The general custom amongst Chicago architects is to allow $3\frac{1}{2}$ inches from the top of the beams to the top of the finished floor. This gives a sufficient space between the beams and flooring for running gas pipes or water pipes, as shown in Fig. 183. Wherever buildings are piped for gas, and especially office buildings, it is absolutely necessary to leave sufficient space between the tops of the steel beams and the bottom of the flooring for running branches to centre outlets.

Wherever the nailing strips cross the floor beams or girders they should be fastened to them by means of iron clamps, made so that one end can be hooked over the flange of the steel beam and the other end driven into the side of the wood strip. When the strips run parallel with the beams it is good practice to nail pieces

of hoop iron across the under side of the strips about 4 feet apart, to hold the strips more firmly in place, as the concrete alone does not hold them with sufficient firmness. The hoop iron strips should be $1\frac{1}{2}$x$\frac{1}{8}$ inch and 10 inches long, and should be secured by two clout nails.

The concrete used for the filling on top of the arches and between the nailing strips should be made of screened boiler cinders, mixed with lime mortar gauged with plaster of Paris or Portland cement, the cinders being used on account of their lightness. The concrete must become thoroughly dry before the flooring is laid. As this requires considerable time, dry cinders without any lime or cement has been used in a few office buildings where it was necessary to rush their completion. The best architects, however do not recommend the use of dry cinders when it can be avoided.

Occasionally, where the beams are of unusually long span, a 10-inch or 12-inch arch is set between 15 or 20-inch beams. In such cases it is better to fill in on top of the arches with partition tile or ∩-shaped tile made for the purpose.

If the floors are to be tiled the concrete between the bottom of the tiles and the top of the arch should be made of Portland cement, sand and crushed stone.

Wooden floors should be laid continuously over the entire area to be covered, without reference to partitions, where the same are liable to be changed to suit tenants. Permanent partitions should be erected before the floors are laid.

Fig. 183 shows the floor construction used in the "Fair" Building, Chicago, Jenney & Mundie, architects, and also the fireproofing of the columns. This cut is also typical of many other buildings recently erected in Chicago.

303. Segmental Tile Arches.—Where a flat ceiling is not essential, and for warehouses, factories, breweries, etc., the segmental arch gives the strongest, best and cheapest (considering the saving in ironwork) fireproof floor that can be built of tile. Segmental arches can be used for spans up to 20 feet, thus dispensing entirely with the usual floor beams; they also effect a considerable saving in the dead weight of the floor, thereby enabling the columns and girders to be made lighter.

There are at present two distinct systems of segmental arches in vogue in this country.

Hollow Tile Segmental Arches.—The most common form of segmental arch is that shown in Fig. 184, which is made of hollow

blocks, usually 4, 5, 6 or 8 inches square and 12 inches long, the tile being laid so as to break joint longitudinally of the arch. Nearly all manufacturers of hollow tiling make one or more shapes for segmental arches, and also different styles of skewbacks to use with them. Hollow tiles for segmental arches are also made both of dense and porous tiling. The latter is generally considered as the best material for this purpose. Segmental arches should have a rise of not less than 1 inch per foot of span, and $1\frac{1}{2}$ inches wherever practicable.

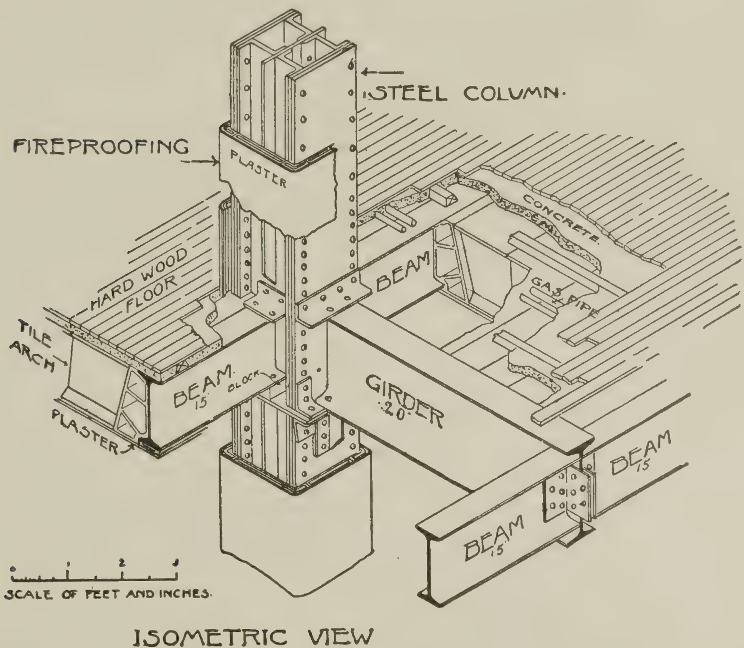


Fig. 183.

With this type of arch it is better to use a very heavy or solid skewback without the flange projection, as the thrust on the skewback is very great where the arch is of wide span. The bottom flange of the beam should be covered with heavy, stiffened wire lath before the skewbacks are set. When plastered the ceiling has the appearance shown in Fig. 184.

If the span of the arch is not more than 8 feet, hollow brick, with raised skewbacks, may be used, as shown in Fig. 185. This makes a very light and strong floor.

The *tie-rods* for segmental arches should be placed just above the bottom flange of the beam, as shown in Fig. 184, and should be protected either by special tiling, made so as to form a paneled effect in the ceiling, or by wire lathing and plaster.

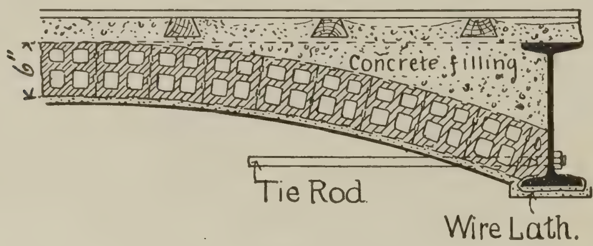


Fig. 184.

Weight and Strength.—The following figures may be taken as a fair average for the weight per square foot of hollow brick or tile segmental arches, exclusive of the concrete and plastering:

Arches 4 inches thick, 20 pounds per square foot; safe span, 8 feet.
Arches 6 inches thick, 30 pounds per square foot; safe span, 16 feet.
Arches 8 inches thick, 40 pounds per square foot; safe span, 20 feet.

The weight of the concrete should be figured for each special case, allowing 120 pounds per cubic foot of concrete. Plastering should be taken at 8 pounds per square foot.

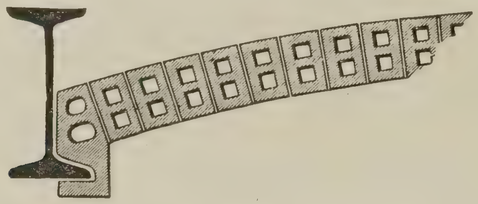


Fig. 185.

The spans for different thicknesses should not exceed those given above, except that for spans of 20 feet about 7 feet of the centre portion may be built of 6-inch tile.

The segmental form of arch is undoubtedly the strongest that can be built, whether of brick, hollow tile or concrete.

In the celebrated Austrian tests* a common brick arch 5½ inches thick and 8 feet span, with a rise of 9.85 inches, carried an eccentric

* *Architecture and Building*, January 4, 1896.

load of 885 pounds per square foot before failing. The failure was then caused by buckling and not by crushing. A porous tile arch of 15 feet 4 inches span, with a rise of 16 inches, built with 6-inch hollow blocks for a distance of 7 feet 8 inches across the centre and with 8-inch blocks for the balance, was tested by loading one side with a pile of bricks measuring 4 feet 6 inches lengthways of the arch and 7 feet 6 inches widthways. When the weight reached 42,000 pounds (1,235 pounds per square foot) the unloaded side commenced to buckle, and in 30 minutes collapsed.*

Segmental arches, with spans not exceeding those given above, built with a rise of 1 inch per foot of span and laid in good cement mortar, may be safely relied upon to carry as much as the beams, when uniformly loaded.

Setting.—Segmental arches are set in the same way as flat tile arches, except that the centres are arched to the desired curve and are suspended at the sides from the beams or girders by hooks passing over the beams. The bottoms of the hooks are made round, and have a thread and wing nut for bringing the centre into its proper place and for lowering it after the arch has set.

Holes are left where the hooks pass through the arch, and after the centres are removed these are substantially plugged with mortar and tile.

304. **"Guastavino" Arch** (Patented, and erected only by R. Guastavino).—This is the other type of segmental tile arch referred to in the previous section. It is not a true segmental arch, but is constructed on the dome principle.

Arch or dome shells are built of small rectangular tiles of hard terra cotta about 6x12 inches and 1 inch thick, cemented together in three or more thicknesses, depending upon the size of the vault. The tiles are laid on arched centres one course at a time, and each course breaks joint with that below. The first layer is usually laid in plaster of Paris and the others in Portland cement. The thickness of the shell is generally increased at the haunches or reinforced by a light arch sprung against the top of the girder web. Each dome generally covers the space between four columns, girders being run from column to column both ways of the building and tied together at their ends. Entire rooms, when surrounded by brick walls and not more than 20x40 feet, may also be covered by a single vault. The

* *Engineering Record*, April 14, 1894.

strength of these vaults, considering their thickness, is very remarkable.

This system does not appear to be applicable to stores and office buildings on account of the shape of the ceiling, but for public buildings and buildings having solid masonry walls or piers, and where a curved soffit is in keeping or desirable, it possesses great advantages. It has been used in a number of buildings in New York and Boston, and in a few instances in other cities. It was used throughout the Boston Public Library.

305. **The Fawcett Ventilated Fireproof Floor.**—This floor is constructed of dense tile and cement concrete, and differs entirely from those previously described.

The tiles are tubular in form, and, instead of being made to form an arch, are used as lintels, as shown in Fig. 186. They are made

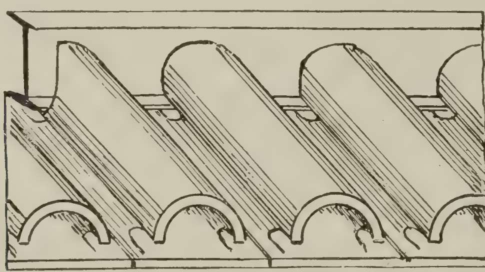


Fig. 186.

of fire or chimney pot clay in pieces about 2 feet long. The floor beams for this system of construction are spaced 2 feet apart from centres, and the lintels are fixed between them with their diagonals at right angles with the beams.

The end of each bay is squared by cutting (during manufacture) an ordinary lintel parallel to the diagonal; the piece cut off, when reversed, goes on the other end. Thus the ends and sides of all lintels are open next the walls. These are called "splits."

The lintels being in position, specially prepared cement concrete is filled in between and over them, which takes a direct bearing upon the *bottom* flange of the beams, thus relieving the lintels of the floor load, which is taken by the iron and concrete, the lintels forming a permanent fireproof centring, reducing the dead weight of the floor about 25 per cent. and saving about half the concrete.

The lintels bear on the beams in such a way as to entirely encase

the bottom flange without being in contact with it, a clear ½-inch space being left for the passage of air.

The peculiar feature of this system is the circulation of air provided through the tubular lintels and under the flanges of the beams. Cold air is admitted (through air bricks in the external walls) into a portion of the open ends or sides of the lintels, and passes through them from bay to bay under the beams, both transversely and longitudinally of the floor, as shown in Fig. 187.

It is claimed that the chief fire-resisting agent in this floor is not so much the terra cotta or the concrete as the *cold air*, and that the circulation of air through the floor and around the beams will actually prevent the iron from ever getting hot.

The Fawcett Company claim that their floors have never been injured by fire and water beyond what could be repaired by replastering the ceiling and redecorating the walls.

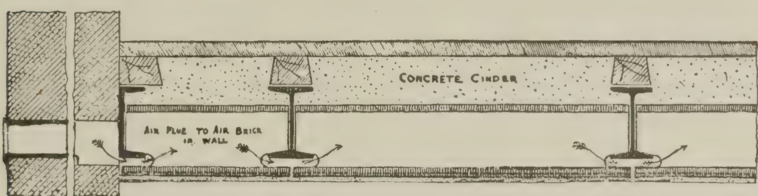


Fig. 187.

The steel floor beams, being spaced so near together, can be made very light (5-inch beams being generally used for office floors, schools, etc., up to 16 feet span), and as the total thickness of the floor from under side of plaster to top of flooring is but 5 inches greater than the depth of the beams, the floors are consequently much thinner than in almost all other systems.

The floor is finished on top by bedding 2x3-inch nailing strips in the concrete above the steel joist, as shown in Fig. 187, and nailing the flooring to these strips in the usual way.

Repeated tests have proven that the strength of the tile and concrete filling is fully equal to that of the beams, so that the carrying capacity of the floor is only limited by that of the beams. For beam spans not exeeding 18 feet, the cost of the structural steel work *in place* does not exceed that of the structural work for the flat arches previously described.

The advantages claimed for this system, aside from its fireproof

qualities, are : Saving in height of story from 6 to 8 inches ; saving in freight, hauling and hoisting, of about 50 per cent.

No tie-rods are required, and a more even distribution of the floor weight on the walls is secured. No centres are required for setting, and ordinary unskilled labor can be employed for all portions of the work.

The weight of the floor is much lighter than that of any other system using tile filling between the beams, with the possible exception of the Guastavino floor.

This floor has been placed in a great many fine buildings in England, and lately in many buildings in Philadelphia and other Eastern cities. It certainly has many good points and deserves investigation.

306. Concrete and Metal Floors.—Within a few years several styles of fireproof floor construction, based upon the use of concrete in combination with iron or steel in various shapes, have been introduced in this country, and a few of them have proved strong competitors of the hollow tile floor. The chief aim in the introduction of these systems has been to obtain a floor that shall have the strength and fireproof qualities of the tile floor, and at the same time be lighter and less expensive.

There are two general classes of concrete floor construction. The first class consists of tension member floors, which in themselves furnish the necessary strength for sustaining the floor from wall to wall, or wall to girder, without the use of floor beams ; and the other class consists of I-beams 5 or 6 feet apart for sustaining the floor, with rods or bars suspended or resting upon the beams, supporting wire cloth, netting or expanded metal, which carries the concrete or plaster filling. Prominent among the first devices mentioned are the Hyatt ribbed metal ties and Portland cement concrete floors built by P. H. Jackson, San Francisco ; the concrete and twisted bar floors built by the Ransome & Smith Company, of Chicago ; and the Lee hollow tile and cable rod floors built by the Lee Fireproof Construction Company, of New York.

Prominent among the I-beam and concrete filling devices are the systems of the Metropolitan Freproofing Company, of Trenton, N. J.; the expanded metal construction companies of St. Louis and New York,* the arch construction of the Roebling system and the flat beam construction of the Columbian Fireproofing Company.

While concrete has been used in construction to resist compressive stress for many centuries, it was not until 1876 that an attempt was made to form concrete beams by imbedding iron in the bottom to

* For description see page 406.

afford the necessary tensile strength which the concrete lacked. The idea was conceived by Mr. Thaddeus Hyatt, an inventor, who made many experimental beams, with the iron introduced in a great variety of ways, as straight ties, with and without anchors and washers; truss rods in various forms, and flat pieces of iron set vertically and laid flat and anchored at intervals along the entire length. These experimental beams were tested and broken by Mr. David Kirkaldy, of London, and the results proved that the iron could be perfectly united with the concrete and that it could be depended upon for its full tensile strength.

The method Mr. Hyatt finally adopted as the best for securing perfect unison of the iron and concrete was to use the iron as thin vertical blades placed near the bottom of the concrete beam or slab, and extending its entire length and bearing on the supports at both ends; these vertical blades to be anchored at intervals of a few inches by round iron wires threaded through holes punched opposite each other in the blades, thus forming a gridiron, which was completely imbedded in the concrete.

The first person in this country to make a practical application of Mr. Hyatt's discovery was Mr. P. H. Jackson, of San Francisco, Cal., who has used a combination of concrete and Hyatt's ties quite extensively in that city for covering sidewalk vaults and for the support of store lintels; also for self-supporting floors.

Tests of concrete beams made by Mr. Jackson are described in the *Architects' and Builders' Pocket Book.*

307. The Ransome & Smith Floor.—While Mr. Jackson was experimenting with the Hyatt ties, Mr. E. L. Ransome, a very successful worker of concrete in San Francisco, conceived the idea of using square bars of iron and steel, twisted their entire length, in place of the flat bars and wires used by Mr. Jackson, as shown in Fig. 188. It was found that these bars were held in the concrete equally as well, if not better, than the other, and that they were much less expensive. None of the iron in the ties is wasted, and it has been demonstrated by careful experiments that the process of twisting the bars to the extent desired strengthens the rods instead of weakening them.

Mr. Ransome patented his improvement in 1884, and since that time it has been extensively used in San Francisco.

The Ransome concrete floors are made in two forms—flat (Fig. 188) and recessed, or paneled (Fig. 188 A). These floors have been used for spans up to 34 feet. No floor beams are required, the floor being

self-supporting from wall to wall (when the building is not more than 30 feet wide), or from wall to girder. The great strength of these floors has been fully demonstrated by actual use in many heavy ware-

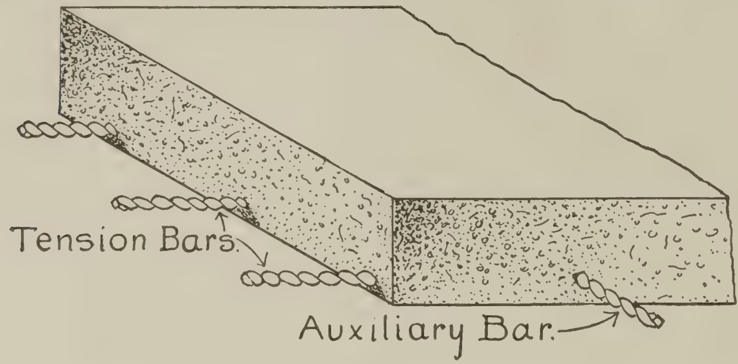


Fig. 188.

houses in various portions of California, as well as in many other buildings.

A section of a flat floor in the California Academy of Science, 15x22 feet, was tested in 1890 with a uniform load of 415 pounds per square foot, and the load left in place for one month. The deflection

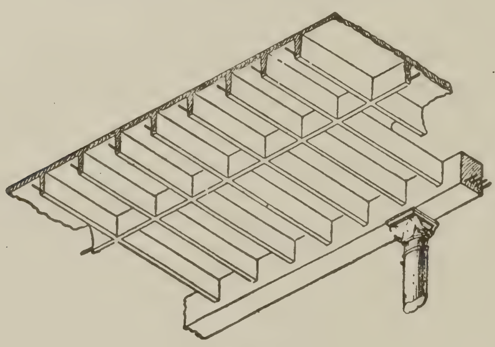


Fig. 188 A.

at the centre of the 22-foot span was only $\frac{1}{8}$ inch. It was estimated by the architects that the saving by using this construction throughout the building, over the ordinary use of steel beams and hollow tile arches of the same strength, and with similar cement-finished floors on top, amounted to fifty cents per square foot of floor.

The flat construction shown in Fig. 188 is the best adapted, of the two, for office buildings, hotels, etc., although the paneled floor, shown in Fig. 188A, has much the greater strength for the same amount of material. The latter construction has been used in several warehouses in California without the use of any steel or iron beams or girders, and has supported very heavy loads for several years.

As a fireproof construction this system is undoubtedly equal to any other construction in use. The patents controlling the use of twisted bars in combination with concrete are now owned by the Ransome & Smith Co., of Chicago, from whom more complete information of their system of flooring may be obtained.

308. The Lee Hollow Tile and Cable Rod Floor.—Mr. Thomas A. Lee, the originator of the end system of hollow tile arches, about the year 1890 patented a system of floor construction which is the same in principle as the Ransome floor. Instead of

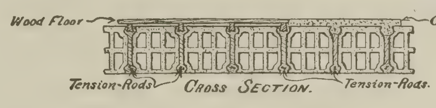


Fig. 189.—Lee Floor.

using concrete to resist the compressive stress, hollow porous tile blocks with square ends and a rod groove along one side near the base are used, as shown in Fig. 189. The tension member consists of cables made of round, drawn steel rods of about $\frac{3}{10}$ of an inch in diameter laid spirally together, usually in two strands. The rods are spaced 8, 10 or 12 inches apart, according to the span and width of tile, and are buried in soft Portland cement placed in the grooves near the bottom of the tile. The cement unites the tiles and cables so as to form a composite beam. The floors extend like a flat plate from wall to wall, or from girder to girder, their thickness being about $\frac{5}{8}$ inch for each foot of span.

Floors and roofs similar to the above have been built in various costly buildings in different portions of this country and in Canada, the spans varying from 10 to 28 feet.

In buildings having solid brick or concrete walls and partitions, these tension member floors may be used to good advantage, but it is doubtful if they ever come into general use in buildings built on the skeleton principle. They require very careful and faithful workmanship and the very best quality of cement to make them safe.

309. The Metropolitan Floor.—This floor, which was for a time known as the "Manhattan" system, and is protected by letters patent, is constructed as follows: Cables, each composed of two galvanized wires (usually of No. 12 gauge) twisted together, are suspended between the top of I-beams, as shown in Fig. 190, and spaced from 1 inch to $1\frac{1}{2}$ inches apart, according to the load which is to be carried. The ends of the cables are secured to the beams by means of hooks 3 inches long made of $\frac{1}{4}$-inch square iron, which grasp the upper flange. A length of gas pipe is laid over the cable midway between the beams to give them a uniform sag. Forms or centres are then placed under the cables, and a composition consisting of 5 parts, by weight, of plaster of Paris and 1 part of wood shavings, mixed with sufficient water to make a thin paste, is poured on.

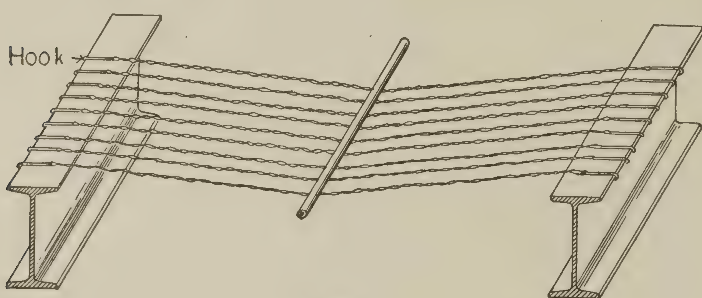


Fig. 190.

As plaster of Paris sets very quickly the resulting floor is sufficiently strong to be used at once under loads, with a surface uniform and level above the top of the beams.

Where a paneled ceiling can be used wire netting is stretched over the beams and the same composition poured around them, fireproofing the beam, as shown at *B*, Fig. 191. Where a flush ceiling is required flat bars are placed on the bottom flanges of the beams and wire netting stretched over them. Forms are then placed underneath and the same composition as in the floor plate poured on, forming a plate about $1\frac{1}{2}$ inches thick and extending 1 inch below the bottom of the beams, as shown at *A*, Fig. 191.

The usual thickness of the floor plate is 4 inches, with beam spacings of from 4 to 6 feet. It will be seen that in principle this floor closely resembles the Ransome tension bar system, as the cables take up the tension and the concrete resists the compressive stress. This combination of steel (in its strongest shape) with concrete is theoret-

ically one of the most perfect forms of fireproof construction, and although defects may be discovered in the details of construction, the system itself seems destined to become of wide application.

No tie-rods between the beams are required in this system, as the floor plate is practically a beam, and transmits only a vertical pressure to the I-beams.

The tests that have been made of this floor construction seem to prove that it is thoroughly fireproof and heat-resisting, and that its ultimate strength for floor plates 4 inches thick and 6 feet span is about 1,500 pounds per square foot, while loads as high as 2,000 pounds have been supported by it.

The remarkably light weight of this floor is one of its chief advantages, the average weight of the floor plate being about 18 pounds per square foot, and the weight of the ceiling plate, without the plastering, 6 pounds. A floor constructed by this method with I-beams

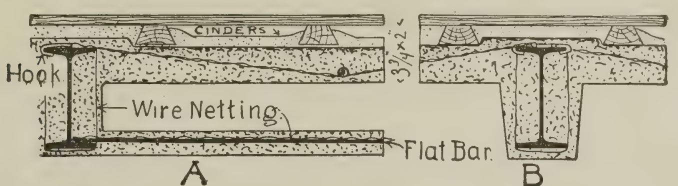


Fig. 191.

6 feet apart would therefore weigh, when all complete and ceiling plastered, less than half as much as the old style dense tile systems.

The greatest objection thus far brought against this floor is the great amount of water used in its construction and the time required for the wood shavings to dry out.

310. Mr. J. Hollis Wells, C. E., in reviewing some tests of fireproof floors made at Trenton, N. J., in 1894, makes the following comparison between the concrete and wire and hollow tile floors: "The method of suspending a fireproof material on wires of proper strength from beam to beam makes a strong homogeneous floor, absolutely fireproof, and each bay or section independent of those adjoining. The hollow tile arch, creating a thrust on the floor beams, depends on tie-rods to counteract it. Tie-rods seldom set in proper place, oftentimes are not screwed up tight, and the construction is weakened. In the suspended floor tie-rods are not used at all; beam is tied to beam from upper flange to upper flange, and a rigid base extends clear across the floor from wall to wall." *

* *Engineering Record*, December 22, 1895.

Various styles of floors have been constructed on the principle of the Metropolitan floor, although nearly all use Portland cement concrete instead of the plaster composition. Wire lathing, expanded metal, and various shaped bars are used for the tension members.

The principal advantage sought in these floors over the terra cotta tile arches is a reduction in the weight of the floor, thereby causing a saving in the steel construction. The floors themselves are also, as a rule, a little cheaper than the tile floors.

The strains in floors of this kind are the same as in those of a beam, the effect of the load being to pull the tension members apart at the bottom and to crush the concrete on top. When the concrete is of the proper thickness, and of good quality, the strength of the floor will be determined by the strength of the tension members.

Several tests of beams made of Portland cement, concrete and wire netting made by the New Jersey Wire Cloth Company, appear to show that only about one-half the strength of the tension members (when of wire cloth) can be developed. In all floors constructed of concrete, plaster or tile, with steel tension members, it is of the first importance that the two materials shall be so closely united that the tension members will not be *drawn through*, or *slip* in the concrete, for the minute this occurs the strength of the floor, *as a beam*, is destroyed. To secure this perfect adhesion, it is necessary that the materials and work shall be of the best quality and not slighted in any way.

311. The Roebling Patent Fireproof Floor.*—This also is a concrete construction, but the concrete, instead of being used as a beam, is entirely in compression, the strength of the floor being due to the resistance of the concrete acting as an arch.

The method of forming the floor and ceiling is well illustrated by Fig. 192. The floor construction consists of a wire cloth arch, stiffened by steel rods, which is sprung between the floor beams and abuts into the seat formed by the web and lower flange of the I-beams. On this wire arch Portland cement concrete is deposited and allowed to harden, making a strong monolithic arched slab between the beams. The ceiling construction consists of supporting rods attached to the lower flanges of the floor beams by a patent clamp, which offsets the rods below the I-beams. Under these rods, and securely laced to them, is placed the Roebling standard lathing, with the stiffening rods crossing the supporting rods at right angles. This

* Controlled by the John A. Roebling's Sons Co.

construction produces a ceiling that is uniformly level over its entire surface, requiring the same amount of plaster over all portions. The ceiling being separate from the floor is not liable to stains, as is frequently the case with tile construction.

The *weight* of finished floor and ceiling, including the plastering underneath and two thicknesses of wood flooring, as given by the Roebling Co., varies from 28 to 53 pounds per square foot, according to the span and depth of beams or girders. This is exclusive of the steel beams. [See also page 405.]

The *strength* of this floor depends, of course, almost entirely upon the concrete—the quality and proportion of the ingredients and the mixing.

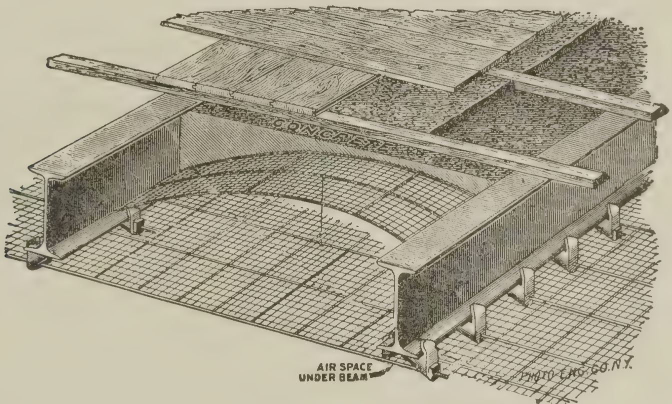


Fig. 192.

Thus far, where the system has been used, only the best grades of imported Portland cement and the best sharp sand have been used. For dwellings and buildings in which the live load never exceeds 100 pounds per square foot, a concrete made of cement, sand and first-class cinder may be employed, with a saving in weight and cost, and at the same time with ample strength.

Various tests of these floors built by the Roebling Sons' Co., with spans varying from $4\frac{1}{2}$ to 5 feet, have shown a carrying capacity, *with no signs of failure*, of from 1,000 to 2,400 pounds per square foot.† Further evidence of the strength of such floors is also furnished by the celebrated "Austrian" tests on concrete arches.* In these tests a concrete arch only 3 inches thick and span of $4\frac{1}{2}$ feet, without

* See *Architecture and Building*, January 4, 1895. † See also page 405.

filling above the haunches, sustained 1,638 pounds per square foot over the entire area *without failure or cracking*, while a similar arch, $3\frac{5}{16}$ inches thick, with span of 8 feet 10 inches and rise of $10\frac{1}{2}$ inches, sustained an *eccentric* load over one-half of the arch of 1,130 pounds per square foot. The arch then failed by *buckling*, and not by compression.

The strength of the Roebling floor, therefore, may be considered ample for any load that may be applied, provided the concrete is of sufficient thickness at the crown and of good quality.

The most economical proportions for this floor, considering also the cost of the steel beams, will generally be obtained by using 10-inch I-beams, spaced as far apart as the loads will permit.

Aside from its strength and fireproof qualities, this construction possesses many practical advantages, a few of which may be briefly mentioned : A perfectly flat ceiling, which may be placed any distance below the beams and which is not liable to discoloration ; a continuous air space between floor and ceiling; it is much lighter than many of the tile floors, and can be adapted to any building or to any load. The ceilings may be either flat, paneled or arched.

No special arrangement of floor beams is required, and the spacings need not be uniform.

The floor is not *easily damaged;* openings of any size may be cut through the concrete to neat dimensions, the wire cloth preventing the concrete from flaking away on the under side.

Where buildings must be erected with great rapidity, or in winter weather, this system is especially desirable. No wood centring is required, and as the arch wire is made to dimensions and bent to the correct curve at the mill, the wire arches can be put in place very quickly and in any kind of weather. Once in place they afford a protection to workmen, as they possess sufficient strength in themselves to sustain a considerable load, or to intercept a person falling from the beams above. The wire arches are generally set so as to keep within two stories of the masons. As Portland cement is used for the concrete, the latter can also be safely mixed in quite cold weather. The floors are safe and available for use two days after the concrete has been applied.

The cost of this system should not exceed that of other systems using Portland cement or tile, and in many instances would probably be less.

312. The "Columbian" System of Fireproof Floors.*— This system is also one of concrete construction, the shape of the concrete being very much the same as in the Metropolitan floor. In this floor, however, the concrete, instead of being supported by wires or netting, is supported by ribbed steel bars of a special shape, suspended from the steel I-beams and supported on edge by means of steel stirrups, which have the profile of the bar cut in them, as shown in Fig. 193. After the bars are set in place a wooden form is suspended beneath them and a layer of Portland cement concrete is laid on top, flush with the top of the beams and completely surrounding the ribbed steel bars.

If a level ceiling beneath the beams is desired it is constructed independently of the floor by using 1-inch section ribbed bars, resting on the bottom flanges of the I-beams, and filling between and around them with concrete, in the same way as is done for the floors.

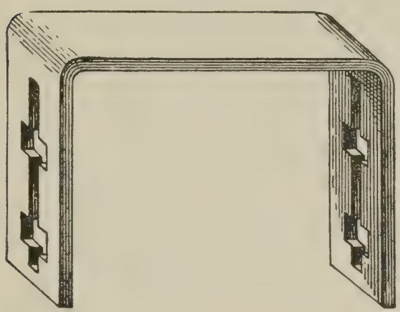


Fig. 193.

The system of floor and ceiling construction is plainly shown by the section drawing, Fig. 194.

Three sizes of bars are used for the floor construction— $2\frac{1}{2}$-inch, 2-inch and $1\frac{1}{2}$-inch, and these are spaced at different distances apart, according to the span and the weight to be supported. The $2\frac{1}{2}$-inch bars are used only in warehouses, heavy storage buildings, etc.; the 2-inch bar for floors in office buildings and where the loads do not exceed 200 pounds per square foot. The $1\frac{1}{2}$-inch bar gives sufficient strength for floors in residences, apartment houses, etc. The shape of the 2-inch and $2\frac{1}{2}$-inch bars is shown by the hole in the stirrup, Fig. 193. The $1\frac{1}{2}$-inch bar has only one rib. The stirrups are made of $2 \times \frac{3}{16}$-inch steel. The usual spacing of the bars is about 20 inches.

The concrete recommended by the Columbian Co., and generally used, is composed of 1 part Portland cement, 2 of sand and 5 of crushed furnace slag, although broken brick and certain kinds of rock are also sometimes used.

The most economical spacing of the floor beams for this construction

* Patents controlled by the Columbian Fireproofing Co.

is 6 feet from centre to centre of beams for the double construction shown in Fig. 194 and 7 feet for paneled construction, although either construction can be adapted to spans up to 8 feet. It is also not necessary that the spacing of the beams be uniform, and no special framing is required for this system, as it can be readily adapted to any plan suitable for any of the flat floor constructions described, although with this system the beams can often be made lighter or spaced farther apart, owing to the decreased dead weight of the floor.

In most classes of buildings other than offices and dwellings the double construction is not necessary, as the bottom of the floor construction answers for the ceiling, and by enclosing the beams and girders with concrete or tile, a neat paneled effect is produced, and

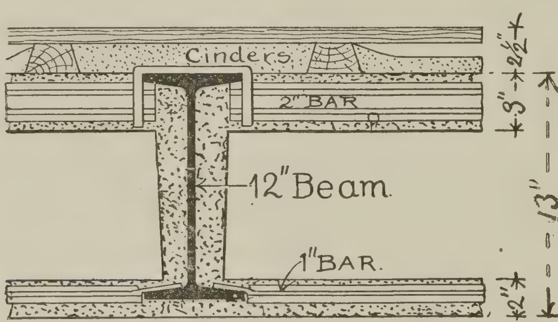


Fig. 194.

the height of the story increased or the total height of the building decreased, as preferred.

Fig. 195 shows two styles of girder casings used in connection with this system, both providing for an air space completely around the steel. The casing shown at *A* is made of concrete slabs, supported by iron clamps or ties, which are completely imbedded in and insulated by the bottom slab—a very important provision. The casing shown at *B* is made of hollow tile, thus providing two air spaces on each side of the beam and one underneath. Concealed anchors are also used for this casing.

This floor may be finished on top in the usual way by imbedding nailing strips in cinder filling, or $2\frac{1}{2}$x$1\frac{1}{4}$-inch strips (not beveled) may be nailed directly to the concrete floor and the filling omitted. Nailing strips have been applied in this manner in several large buildings, and, it is claimed, with the best results.

The weight of this system of floor construction, exclusive of the I-beams, plastering, nailing strips and flooring, is as follows:

For $2\frac{1}{2}$-inch bars,	4 inches of concrete,	40 pounds per square foot.
For 2-inch bars,	3 inches of concrete,	30 pounds per square foot.
For $1\frac{1}{2}$-inch bars,	$2\frac{1}{2}$ inches of concrete,	24 pounds per square foot.

The level ceiling shown in Fig. 194 (2 inches thick) weighs 20 pounds per square foot.

Strength.—The Columbian Co. guarantee that their 3-inch floor, 6 feet span, will support 200 pounds per square foot; the 4-inch floor, 6 feet span, 600 pounds per square foot, and the $2\frac{1}{2}$-inch floor, 5 feet span, 150 pounds per square foot, *with factor of safety of four*, and the published tests that have been made of this system would

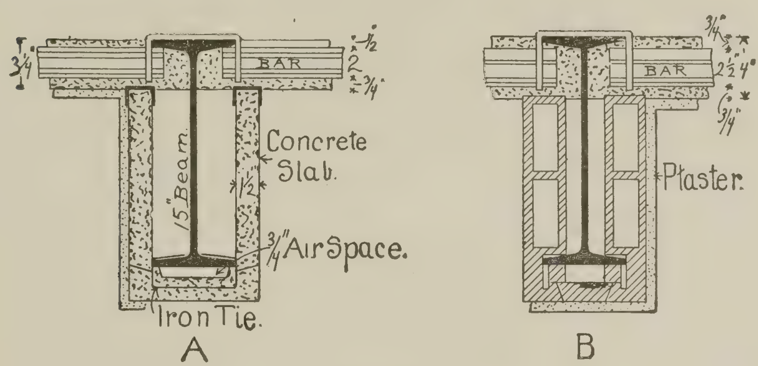


Fig. 195.

appear to sustain the guarantee. This construction appears to be especially strong to resist drop or jarring loads. A ram weighing 238 pounds was dropped from the height of 8 feet on the centre of an 8-foot span several times without perceptible effect on the floor. (The bars in this floor were $2\frac{1}{2}$ inches, spaced 20 inches apart.) It is also claimed that in case of overloading the floor will not fail suddenly, but that the bars will gradually bend, thus giving warning of danger.

The complete fireproof quality of this floor, which is, of course, the same as that of the Roebling and other Portland cement floors, was proved by a severe test of fire and water while the floor was uniformly loaded with 750 pounds per square foot.

Economy.—While this floor is thoroughly fireproof and waterproof and possesses ample strength and remarkable rigidity, it also possesses several advantages of a practical and economical nature.

No tie-rods are required, and no punching of the I-beams is necessary, except where they are framed to the girders or around openings. Lighter beams may be employed than where heavier types of floor construction are used. No channels are required in outside masonry walls.

In buildings having brick partitions and solid masonry walls this floor, with paneled ceiling, is especially economical, as no channels are required, and the beams require no punching, except for anchoring their ends to the walls. This floor can be constructed as rapidly as any and can be carried out without difficulty in winter weather.

Holes may be cut at any place in the floor by plumbers or electricians without injuring the strength of the floor, and the holes may be cut as small or as large as may be necessary.

312. Actual Weight of Fireproof Floors.—In the spring of 1895 a series of fireproofing tests was made in the basement and first story of a building then being erected in Boston, a full description of which may be found in the *American Architect* of September 7, 1895.

The question of the comparative weights of the different floor construction having been raised, it was decided to weigh a section of each.

The debris from the fires was removed from the houses, the floors broken down, care being taken to preserve all the material that had entered into their construction, and it was then weighed on platform scales. The data thus gathered are tabulated below.

TEST NO.	CONSTRUCTION.	AREA OF SECTION.	TOTAL WEIGHT.	WEIGHT PER SQ. FT.
1.	Roebling System..........	18 sq. ft.	1,295 lbs.	72 lbs.
2.	Metropolitan System, panel construction...........	18 "	427 "	23.7 "
3.	Expanded Metal Co.'s System..................	22.5 "	1,697 "	75.4 "
3[a]	Same as No. 3, with additional flat ceiling.......	22.5 "	1,814 "	80.6 "
4.	Eureka System...........	20.25 "	1,648 "	81.3
5.	12-inch porous hollow tile arch blocks covered with concrete 2 inches thick..	20.25 "	1,781 "	87.95 "

In considering this table it should be noted that all of the floors, with the exception of No. 2, were plastered on the under side, and were

concreted on top, ready to receive the wood floors. The plastering on No. 5 fell during the fire test and was removed with the debris, and, consequently, not weighed with the other material; the weight of the 12-inch floor beams is not included in the weight given above.

313. Selection of a System.—Where there are so many styles of fireproof floors, each claiming to be superior to the others, it is difficult for the architect to decide on a particular construction. The choice of a system of fireproofing is more apt to be decided by the question of cost than by other considerations. The relative cost of different systems will also vary somewhat with the locality and distance from the manufacturing centres. It should be ascertained, before fully deciding on the system to be used, by obtaining approximate bids from the different fireproofing companies, most of whom are always ready to submit such bids.

The author believes that either of the floor systems described herein, if properly constructed with materials of good quality, will make a thoroughly fireproof floor, although where the danger from a severe conflagration is especially imminent, porous tiling is generally considered as the superior non-conducting material.

The question of strength hardly needs to be considered except for floors for warehouses and heavy storage buildings, as either of the systems possess sufficient strength for other buildings if the sections are not made too light or the spans too great.

Where heavy loads are to be carried, however, those systems which have *uniformly* developed the greatest strength should be selected. The question of lightness is often one of considerable importance, especially in dwellings, apartment houses, hotels and office buildings. Very often the considerations of speed in erection and quickness in drying out, the adaptability to putting in place in cold weather, etc., are sufficient to decide in favor of a particular system.

Many engineers still favor the use of dense or porous tiles for fireproofing, and these materials are undoubtedly of great value, and possibly the best for certain conditions, but the combinations of iron with Portland cement concrete are rapidly gaining in favor, and the author believes that concrete, when properly combined with the metal, makes a very strong and thoroughly fireproof construction, and that it has now been used for a sufficient length of time to fully demonstrate its adaptability to floor construction.

With nearly all systems of fireproofing the efficiency of the construction depends very largely upon the character of the workman-

ship and the quality of the materials used. When it is desirable to use as much unskilled labor as possible, the Fawcett, Roebling or Columbian floors can be used to advantage, an intelligent and honest foreman being the only skilled person required.

FIREPROOF ROOFS.

314. Flat Roofs.—Nearly all fireproof office buildings, apartment houses, hotels and warehouses have "flat" roofs, pitched just enough—generally from $\frac{1}{4}$ to $\frac{1}{2}$ an inch to the foot—to cause the water to run to the lowest point. It is easier to make a flat roof thoroughly fireproof than it is a pitch roof, and the flat roof is also much less expensive.

The usual, and also the best, method of constructing flat roofs on fireproof buildings is to build the roof in the same way as the floors, giving the beams the same pitch as the roof. If the filling between the beams is of hollow tile, segmental arches, or flat arches with raised skewbacks, may be used with economy.

When any of the patented systems of fireproof construction is used, the roof, if flat, is almost invariably constructed in the same way as the floor, only using a little lighter section.

After the filling between the beams is set, the roof should be covered with cement mortar or concrete, sufficient to bring it to a uniform surface and to give the desired pitch.

The roofing may be either of tin, copper, rock asphalt or composition, finished on top with gravel or vitrified tile set in Portland cement. Coal tar, pitch and asphalt have a natural affinity for cement or terra cotta, and adhere readily to them without the use of fastenings. If a tin or copper covering is to be used, porous tiling is especially adapted for the beam filling, as the nails for the tin cleats may be driven directly into the tiling. Before applying the tin the entire surface of the roof should be plastered smooth with $\frac{3}{4}$ of an inch of cement mortar to form a smooth, hard surface on which to hammer down the tin. Thin, hollow tiles, set between 3x3-inch T-irons, are also occasionally used for roofs.

Whatever kind of tiling or filling is used it should be of such construction that the bottom flanges of the beams or T-irons will be well protected, and if tiling is used it should receive a heavy coat of plaster under the beams, if not elsewhere. The supporting girders and columns should also be well protected, either with hollow tiles, concrete or plastering on metal lathing.

315. Mansard and Pitch Roofs.—For mansard roofs the most economical method of construction is by using I-beams, set 5 to 7 feet apart, and filled in between with 3-inch hollow partition tile, provision for nailing slate being made by attaching $1\frac{1}{4}$x2-inch wood strips to the outer face of the tile, the strips being set at the proper distances apart to receive the slate, the spaces between the strips being then plastered flush and smooth with cement mortar. In case of a severe conflagration the slate would probably be destroyed, and the wooden strips might be consumed, but the damage could go no farther. In place of partition tile porous terra cotta bricks or blocks may be used for filling between the I-beams. For roofs where the pitch is not over 45°, 3x3-inch T-irons, set 16 inches between centres and filled in with slabs of porous terra cotta, make a very desirable roof. If slates or roofing tiles are used they may be nailed directly into the porous tiles, or, if it is desired to use hollow tile, strips of wood may be nailed to the tile for receiving the slate and the spaces between the strips filled in with cement.

All truss members, purlines, etc., should be protected from fire and heat either by wire lathing or by porous tiling, covered with a heavy coat of plaster. Probably the best and most thorough method of protecting truss members is by first covering them with $1\frac{1}{2}$-inch slabs of porous tiling and wrapping them securely with stiffened wire lathing, which should then be covered with a heavy coat of cement plaster.

316. Ceilings.—In office buildings having a flat roof there is generally an air space or attic between the roof and ceiling of the upper story, varying from 3 to 5 feet in height. This space is often utilized for running pipes, wires, etc. Buildings having pitched roofs necessarily require a ceiling below to give a proper finish to the rooms in the upper story and to make the rooms comfortable. In office buildings the ceiling under the roof is generally of a similar construction to that of the floors, although when systems like the Roebling, Columbian or Metropolitan are used in the building only the suspended ceiling plate is required between the beams, and the latter may be made very light.

Under pitch roofs (and sometimes under flat roofs) a suspended ceiling is generally used. T-bars (usually 3x3 inches in size) are hung from the roof construction by means of light rods, and the ceiling constructed either by means of wire or expanded metal lathing laced to light angles, or flat bars placed between the T's, or by thin tiles of dense or porous terra cotta. If a tile ceiling is to be used, the author believes that porous or semi-porous terra cotta should be given the

preference. Whichever material is used, the shape of the tiles should be such that they will drop below the flanges of the T's, so as to protect the metal.

Fig. 196 shows the usual section of porous ceiling tile, and Fig. 197 an improved shape of semi-porous ceiling tile made by the Pioneer Co. The width of the porous tile is 16 inches for 2-inch tile and 18, 20 and 24 inches for 3-inch tile. The 2-inch tiles weigh 11 pounds

Fig 196.

and the 3-inch tiles 15 pounds per square foot, exclusive of the plastering. The tiles shown in Fig. 197 are 3 inches thick and weigh $14\frac{1}{2}$ pounds per square foot.

Suspended ceilings of wire lath and plaster weigh only about 12 pounds per square foot, including the plastering.

Whether tile or metal lathing is used for the ceiling, the webs of the T's should be covered with plaster or cinder concrete, to protect them from heat.

317. Girder and Column Casings.—The columns and girders are more exposed to intense heat than the floor beams, and should be protected in the most efficient manner possible, as any expansion in the columns or girders would have a most disastrous effect.

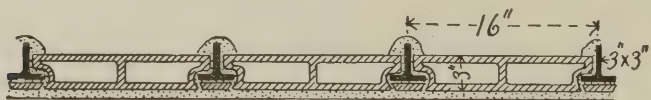


Fig 197.

Columns and girders are also more exposed to the streams of water, which tend to dislodge or break through the casing. As a rule, the manner in which these portions of the structural work are protected depends largely upon the system of floor construction employed. Naturally the parties having the contract for the fireproofing of the floors generally wish to use their system, or materials, for protecting the columns and girders, and thus the question of cost often works to the disadvantage of the better system.

In buildings with tile filling between the floor beams the columns and girders are usually cased with tiles; when one of the concrete

systems of floor construction is adopted, the same material is, as a rule, employed for protecting these members, although there is no necessity for using the same material in both cases.

The unbiased opinion of architectural engineers and those who have made a study of fire protection is, the author believes, in favor of solid porous tiling for girder and column casings. The author believes that the best possible protection for these members will be obtained by using solid blocks of porous terra cotta, well secured to the metal, and then covered with wire or expanded metal lathing plastered with hard mortar, such as "Acme" or "King's Windsor," the metal lathing serving principally as a protection from the blocks becoming dislodged.

Girders.—The usual forms of dense or porous tile casings for girders are shown in Fig. 198. Shapes very similar to these are made by

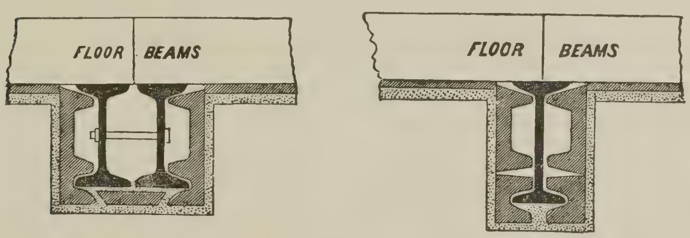


Fig. 198.

all the manufacturers of both dense and porous tiling. Casings of dense tiling should preferably be made hollow, thus giving a second air space, as shown in Fig. 195, *B*. Methods of casing girders with metal lathing will be shown in Chapter XI.

318. Columns.—The protection of the columns, especially in a very high building, should be considered as the most important portion of the fireproofing, although in too many cases it is slighted even to a dangerous extent. The Chicago building ordinance is quite explicit in its requirements for the protection of columns, and forms a good guide for architects elsewhere to follow. These requirements are as follows:

SEC. 108. In the case of buildings of Class I. the coverings for columns shall be, if of brick, not less than 8 inches thick; if of hollow tile, these coverings shall be in two consecutive layers, each not less than $2\frac{1}{2}$ inches thick. If the fireproof covering is made of porous terra cotta, it shall consist of at least two layers not less than 2 inches thick each. Whether hollow tile or porous terra cotta is used, the two consecutive layers shall be so applied that neither the vertical nor the horizontal joints

in the same shall be opposite each other, and each course shall be so anchored and bonded within itself as to form an independent and stable structure.

SEC. 109. In places where there is trucking or wheeling or other handling of packages of any kind, the lower 5 feet of the fireproofing of such pillars shall be encased in a protective covering either of sheet iron or oak plank, which covering shall be kept continually in good repair.

SEC. 111. In buildings belonging to Class II. the fireproof covering for internal columns is to be made the same as specified for the buildings of Classes I. and IV., excepting only that but one covering of hollow tile or porous terra cotta, and but two layers of any covering made of plastering on metallic lath, are to be used.

The most common and cheapest method of fireproofing interior columns has been through the use of shells of dense terra cotta surrounding the column, the separate tiles being usually clamped or hooked together, but not to the metal work. This method has not proved altogether successful.

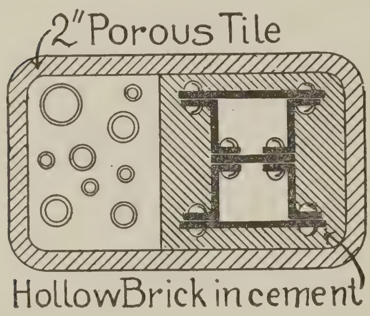


Fig. 199.

"The use of dense tiles is only to be recommended when such tiles are hollow, with a proper air space around the metal column, and even then experience seems to show that the hard tile is in no way as satisfactory under great heat as the more porous kinds."*

Solid blocks of porous tiling at least 2 inches thick, well bedded against the metal column and secured by copper wire wound around the column outside of the casing, seems to be the most approved method of insulation.

The custom has been quite general of running the water and gas pipes beside the metal columns and inside the fireproof casing. When this is done the protection at the floors is often very imperfectly made, and the custom is not now approved.

The best method of running and concealing the pipes is that shown in Fig. 199, which represents the fireproofing of the columns in the first eight stories of the newer portion of the Monadnock Building in Chicago.

Fig. 200 shows a few of the best shapes of dense tile covering. The tile shown at *A* may be used for any size or shape (except round) of column by varying the width of filling pieces *a*.

* Joseph K. Freitag, C E., in *Architectural Engineering.*

Columns are also occasionally protected by surrounding them with a thick coating of concrete. When the concrete is formed in place so as to make a monolithic shell, extending 3 or 4 inches beyond the metal, this should make a very efficient protection.

Methods of protecting columns by metal lathing and plaster are described in Chapter XI.

319. Partitions.—The partitions in fireproof buildings should be built either of brick, tile or iron studding, covered with metal lath and plaster. Brick partitions, when not less than 12 inches thick, may be considered as fireproof, but they are now seldom used except where they can be utilized to support the floors.

In the modern fireproof office building, hotel or apartment house the floors are supported, except at the walls, entirely by columns and girders, and the partitions are almost universally constructed either

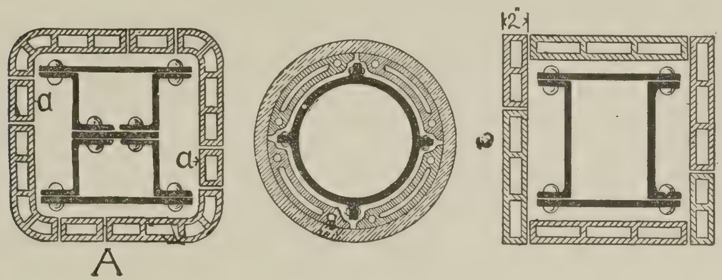


Fig. 200.

of hollow tile, or of thin, solid porous tiles, or metal lath and plaster. Hollow tile are probably the most extensively used for this purpose, although "thin" partitions (from $1\frac{1}{2}$ to 2 inches thick) are coming into quite general use in office buildings.

Partition tiles are made of the same materials and possess the same characteristics as those used in floor construction. Both dense and porous tiles are used for this purpose, porous tiles probably the most extensively, owing to their property of receiving and holding nails.

Partition tiles are made in thicknesses varying from 2 to 6 inches, but the 4-inch blocks are most commonly used. The tiles are generally 12x12 or 6x12 inches on the face. They may be set with the hollows running vertically or horizontally, either construction being sufficiently strong; the horizontal construction, however, has the advantage of a better bonded mortar joint. When the tiles are laid vertically they are frequently clamped together; when laid horizontally a certain

number of tile should be set vertically to accommodate the gas pipes. When the latter are located before the partitions are set the tile may be cut and built around the pipes, or special recessed tile may be used, as shown in Fig. 201. Whether laid vertically or horizontally, the blocks should always be set so as to break joint with each other.

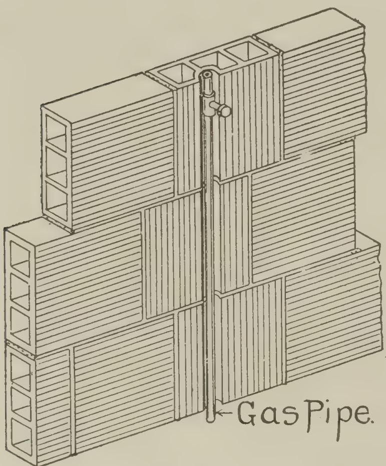


Fig. 201.

For setting the tiles or blocks, lime mortar, to which a small proportion of natural cement is added, is generally used. Acme cement plaster has recently been used for this purpose with excellent results, as it adheres to the tiling even better than natural cements.

At all openings in partitions rough wood frames are set, as shown in Fig. 202, to stiffen the jambs and to afford grounds for the plaster and nailings for the finished frames and casings.

If dense tiles are used for the partitions it is necessary to build in wooden bricks or ½-inch strips in the horizontal or vertical joints to form nailings for the base, chair rail and picture moulding, or courses of porous tiles may be inserted at these places. When porous tiles are used the wood blocks or strips are generally omitted, although experience has shown that porous tiles do not hold the nails quite so securely as wood.

Hollow tile partitions are generally laid on top of the finished floor if there is the least likelihood of their ever being taken down, and, as they are not fastened in any way to the floor or ceiling, they can very easily be removed or changed to suit tenants.

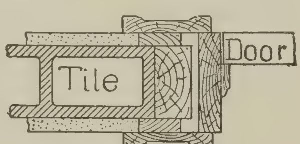


Fig. 202.

The weight of hollow tile partitions per square foot, *plastered both sides*, will average as follows :

3-inch dense tile......27 pounds.	3-inch porous tile......24 pounds.
4-inch dense tile......29 pounds.	4-inch porous tile......29 pounds.
5-inch dense tile......32 pounds.	5-inch porous tile......35 pounds.
6-inch dense tile......36 pounds.	6-inch porous tile......39 pounds.

320. Thin Partitions.—In order to economize the floor space as much as possible, devices have been introduced for constructing partitions that, when plastered both sides, will be only from $1\frac{1}{2}$ to $2\frac{3}{4}$ inches thick. Such partitions are now commonly designated as "thin" partitions. There are a number of devices for constructing thin partitions, nearly all of them using $1\frac{1}{2}$-inch steel studding, to which expanded metal or wire lathing is applied, and sometimes burlap. These constructions are generally erected by the plasterer, and will be described in Chapter XI.

Henry Maurer & Son have patented a partition made of 2-inch blocks of solid porous terra cotta, each block being connected to the other by a galvanized iron clamp. The bottom and top courses are also secured to the floor and ceiling by means of a galvanized iron shoe. No other supports in the shape of ironwork are necessary, and it is claimed that the partition is very stiff. The blocks can be put up by either carpenter or mason. The thickness of the partition, when plastered both sides, is 3 inches, and the weight per square foot, including plastering, 20 pounds.

The Lee Construction Co. also have a patented thin partition, which is made of exceedingly light and porous plates of porous tiling, with tension rods of twisted steel wires placed on each side and imbedded in the plaster. No studding is used. The tension rods, being on the outside of the partition, make the partition very stiff and perfectly straight. This partition is made by the Lee Co. and plastered one coat with hard-setting plaster, such as "Acme" or "Windsor," so that only the finishing coat of plaster need be applied by the plasterer. The Lee Co. also supply and set the rough frames for doors and side lights, and build in all nailing blocks for the base, chair rail and picture mould. The thickness of this partition when finished is 2 inches for stories 13 feet high, $2\frac{1}{2}$ inches for stories from 13 to 15 feet, 3 inches for stories 15 to 18 feet and 4 inches for stories 20 feet high. This partition was used throughout the fifteen-story Syndicate Building in New York City.

321. Wall Furrings.—It is generally customary to fur the basement walls of fireproof buildings, and occasionally the walls above, with tile blocks made for this purpose.

The most common shape of furring tile is that shown in Fig. 203, the blocks being 12 inches square and 2 inches thick, although furring tile are made $1\frac{1}{2}$ inches thick, and in both larger and smaller sizes. They are also made of both dense and porous tiling. The latter possesses the advantage that nailing strips are not required,

but it is doubtful if they offer as good protection from moisture as the harder burned fire clay tiles.

The tiles are laid against the walls in ordinary lime and cement mortar with broken joints, the hollows always running vertically.

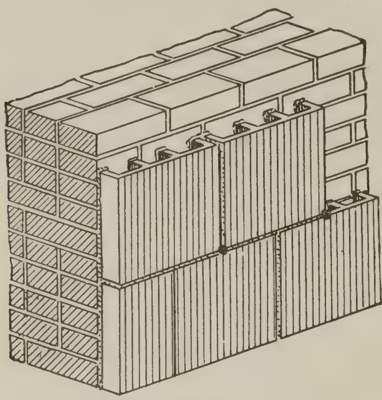


Fig. 203.

Flat-headed nails are driven at the joints into the brickwork to secure the tiles until the mortar has set. When dense furring tile are used, ½-inch strips of wood should be laid in the joints, either vertical

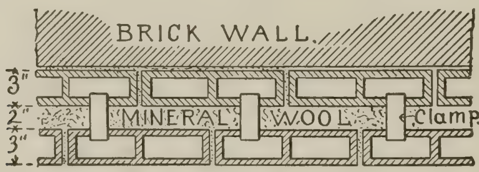


Fig. 204.

or horizontal, to receive the grounds or wood finish. Three-inch hollow partition blocks are also sometimes used for furring.

Fig. 204 shows a good method of furring the walls of rooms used for cold storage, etc.

Chapter X.

IRON AND STEEL SUPPORTS FOR MASON WORK.—SKELETON CONSTRUCTION.

322. Although constructions of iron and steel do not properly come within the scope of this volume, there are so many places where metal work is used in connection with brick, stone and terra cotta that it has been thought desirable to briefly describe the most common forms of iron and steel construction used for supporting masonry walls, and the various minor details of metal work used in connection with the mason work.

Girders and Lintels.—All openings in masonry walls which it is not feasible to span with arches should have iron or steel lintels or girders to support the mason work above. The objections to wooden beams for supporting mason work are given in Section 255.

Since the price of rolled steel has been so greatly reduced, girders and lintels for supporting brick and stone walls are almost universally formed of steel I-beams, or girders built up of steel plates and angle bars. Except for very wide spans and exceptionally heavy loads, steel I-beams may be most economically used for such supports. As a rule, at least two beams should be used to support a 9-inch or 12-inch wall, and three beams for a 16-inch wall, the size of the beams, of course, depending upon the weight to be supported. The beams should be connected at their ends, and every 4 or 5 feet between with bolts and cast iron separators, cast so as to exactly fit between the beams. The girders should have a bearing at each end of at least 6 inches, and should also rest on cast iron bearing plates of ample size.

If the wall to be supported is of brick, the first course above the girder should be laid all headers. The width of the girder is generally made 2 inches less than that of the wall. In calculating the weight to be supported by a girder, much depends upon the structure of the wall above. If the wall is without openings, and does not support floor beams, only the portion of the wall included within the

dotted lines, Fig. 205, need be considered as being supported by the girder. The beams in that case, however, should be made very stiff, so as to have little deflection. If there are several openings above the girder, and especially if there be a pier over the centre of the girder,

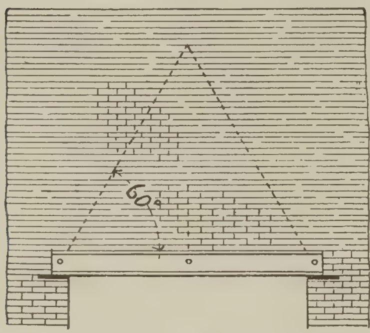


Fig. 205.

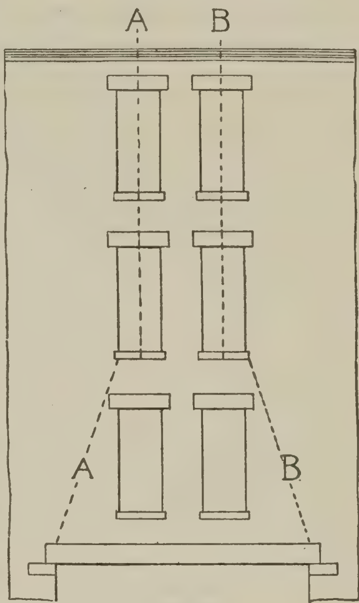


Fig. 206.

as shown in Fig. 206, then the manner in which the weight bears on the girder should be carefully considered. In a case such as is shown in Fig. 206 the entire dead weight included between the dotted lines *A A* and *B B* should be considered as coming on the girder, and proper allowance made for the load being mostly concentrated at the centre.

Steel lintels for supporting stone or terra cotta caps and flat arches are described in Section 190.

323. Cast Iron Lintels.—Lintels of cast iron were at one time extensively used for supporting brick walls over store fronts and door openings, and even at the present time are used to some extent. On account of the brittle character of this metal, however, and its low tensile strength, it should not be used for beams subjected to a moving load, such as floors upon which heavy articles are moved.

Cast iron beams of long span are also not as economical as those made of rolled steel. About the only places, therefore, in which cast iron lintels may be suitably and economically used, are over store fronts where the span does not exceed 8 feet, and over door openings in unfinished brick partitions where a flat head is necessary. The

relative economy between cast iron and steel lintels will depend largely upon the distance from the rolling mills and upon freight rates. Foundries for casting iron are much more widely distributed than rolling mills, so that castings of almost any shape can usually be obtained in any city of twenty thousand inhabitants, while mills for rolling steel beams are comparatively few in number and located mostly in the extreme eastern portion of the country.

The common shape for cast lintels over door openings is that shown

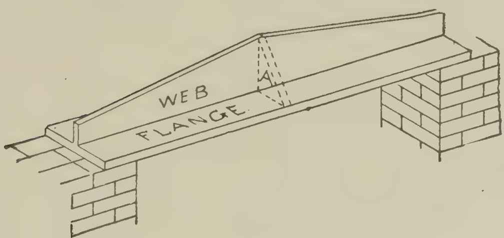


Fig. 207.

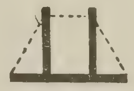


Fig. 208.

in Fig. 207. The width of the flange is usually made the full thickness of the wall, and the extreme height of the lintel at the centre not less than two-thirds nor greater than the width of the flange. The strength of the lintel may be somewhat increased by stiffening the web at the centre by brackets, as shown by dotted lines at A.

Where the width of the flange must be over 16 inches two webs should be used, as shown by the section drawing, Fig. 208. For handling and moulding it is best not to make the flange more than 24 inches wide; if a greater width than this is required, several lintels

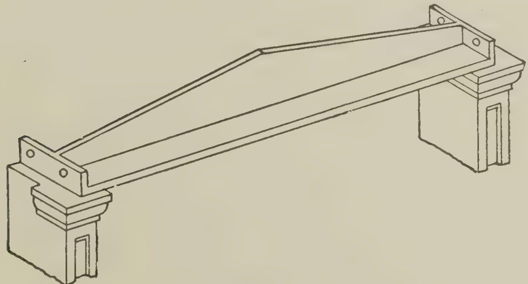


Fig. 209.

should be placed side by side. The thickness of the metal should not be less than $\frac{3}{4}$ inch, and the web should be about $\frac{1}{8}$ inch thicker than the flange.

When proportioned as above the *strength of the lintel* to support a *dead* load may be safely made equal to

$$\frac{9700 \times \text{area of bottom flange} \times \text{extreme depth}}{\text{span in inches.}}$$

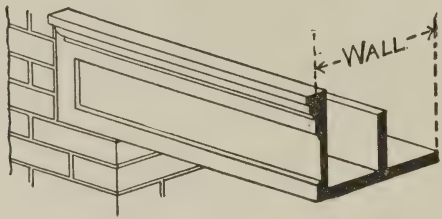


Fig. 210.—Store Front Lintel.

Thus a lintel of 6 feet clear span with 12-inch by $\frac{3}{4}$-inch flange and extreme depth of 12 inches should safely support

$$\frac{9700 \times 9 \times 12}{72} = 14{,}550 \text{ pounds.}$$

Lintels over store fronts should be made with ribs at the ends, as shown in Fig. 209, with holes for bolting the lintels to each other and to columns. Store front lintels are also occasionally made as shown in Fig. 210, to give a finish above the openings.

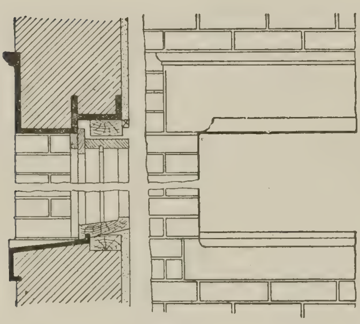


Fig. 211.

Fig. 211 shows details for cast iron lintel and sill, sometimes used for windows in external walls. The thickness of the metal need not exceed $\frac{3}{8}$ of an inch.

324. Cast Iron Arch Girders are also sometimes used to support brick and stone walls where the opening is from 10 to 30 feet in width. Fig. 212 shows a girder of this kind that was used to support a central tower over the crossing of the nave and transept on St. John's Church, Stockton, California, Mr. A. Page Brown, architect. The clear span is $29\frac{1}{3}$ feet, and the height of the wall above the girder 18 feet. One object in using such a girder in this place was to get the height in the centre without also raising the supports,

which could not be obtained with a steel plate girder. The church has a vaulted ceiling which comes just below the arch of the girder, the tie-rod being exposed.

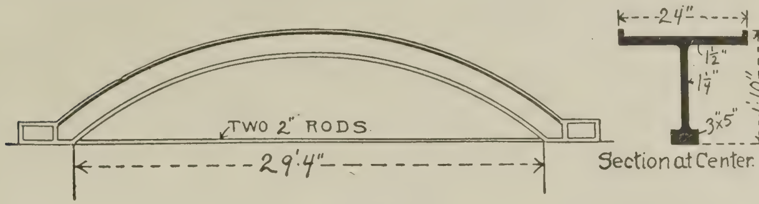


Fig. 212.

The rise of the casting in this case is rather more than common, the usual rise being from $\frac{1}{10}$ to $\frac{1}{8}$ of the span. The end of the girder is generally cast in the shape of a hollow box, with shoulders to receive the ends of the rods. The tie-rod is often made with square ends, and about $\frac{1}{8}$ inch shorter than the casting, and is heated until the expansion permits of its being slipped into its place in the casting. As it cools the contraction binds it tightly into its place. If tightened by means of a screw and nut, the nut and bearings should be dressed to a smooth surface and the rod turned up with a long-handled wrench. It is very essential that the rod shall be fitted in place so tightly that no tensile strain can come on the casting, and, on the other hand, it should not be expanded so as to bring an initial strain on the arch.

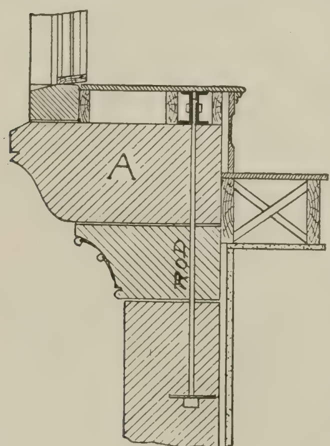


Fig. 213.

This form of girder is comparatively little used now, but there may be conditions, as in the church mentioned above, where it can be used to advantage.

325. Supports for Bay Windows.—Where bay windows having walls of brick, stone or terra cotta start above the first story, it is necessary to support them in some way by metal work.

If the bottom of the bay is of stone, and the projection is not more than 2 feet, the bay may be supported directly from the wall by cor-

beling out the stonework as shown in Fig. 213. The stone *A* should be the full size of the bay if possible, and should be bolted down by means of long rods built into the wall and secured to two channel bars (as in the figure) placed on top of the stone and with their ends built into the main wall.

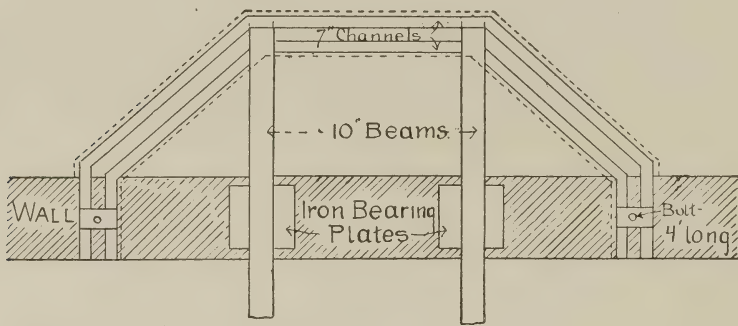


Fig. 214.

If the bottom of the bay is of copper, and at a floor level, the simplest and strongest method of supporting the bay is that shown in Fig. 214.

Steel I-beams are extended across the wall of the story below and framed to a pair of channels, bent to the shape of the bay. The I-beams should be carried far enough inside of the walls to give them a sufficient anchorage to offset the leverage of the outer end, and should be secured to a girder or partition running parallel with the wall or to another steel beam at right angles with them, and forming part of the floor construction.

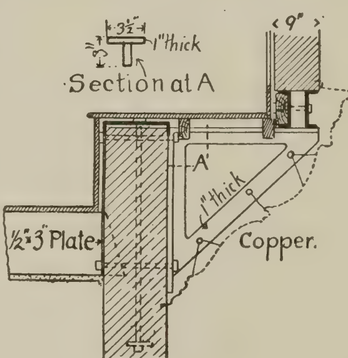


Fig. 215.

The channel bars forming the support for the walls of the bay should also be built into the wall on each side and anchored by iron rods built into the masonry below.

Fig. 215 shows a method of supporting a light bay by cast iron brackets bolted to the wall, which has been used where the bottom of the bay was above the floor line. The bottom of the bay in this

construction may be either of copper or terra cotta, the latter, if used, being suspended from the bracket by hook anchors. If such construction is used a steel channel should be bolted to the top of the wall and extended well into the side walls, to prevent the brackets from pulling away the brickwork. Examples of bay supports in skeleton construction are also shown in Figs. 221 and 222.

326. Wall Supports in Skeleton Construction.—In buildings built on the skeleton plan, now so generally used for high office buildings, all the weight of the walls, including the masonry surrounding the outer columns, is supported by the steel skeleton, at least above the third story. The outer walls of the lower stories, when of stonework, are sometimes supported directly from the foundations, as was the case in the New York Life Building, Chicago.*

When the walls are supported by the steel skeleton they are generally made very thin—about 12 inches, and sometimes only 9 inches thick—and in the more recent buildings the wall is supported at every story, so that the wall in any story could be removed without affecting the wall above or below.

The materials generally used for the outer walls are brick and terra cotta, these being preferred on account of the ease with which they may be handled and the facility with which they may be built about and between the beams and columns. Brick and terra cotta also appear to be about the only suitable materials for the walls of a fireproof building.

It has been found very difficult to attach stonework to the metal frame, and this, together with the low fire-resisting qualities of most building stones, has practically prohibited the use of this material except in the lower stories. In the Reliance Building, Chicago, thin slabs of highly polished granite enclosed in ornamental metal frames were used for casing the columns in the first story.

The general plan of the exterior walls in this class of buildings consists of vertical piers, from 3 to 4 feet wide, which inclose the exterior columns and extend from the bottom to the top of the building. The space between these piers is generally nearly filled by the windows, either flat or in the form of bays, leaving only a small piece of wall, from 4 to 5 feet high, between the tops and bottoms of the windows to be supported by the frame. These portions of wall between the piers and the windows are called spandrels.

The mason work of the piers is generally supported by angle

* Jenney & Mundie, architects.

brackets attached to the columns, and the spandrels are supported by steel beams or girders of various shapes, called spandrel beams. The spandrel beams extend from column to column, and are riveted to them.

The arrangement of the metal work for supporting the spandrel walls will depend largely upon the architectural effect sought by the designer and upon the materials used, so that the details vary somewhat in every building, and often in different portions of the same building. No general rule or form of construction can therefore be given for arranging such supports, but the architect must use such arrangements as seem best suited to the design of the building he has in hand. The following examples, however, will show how the walls

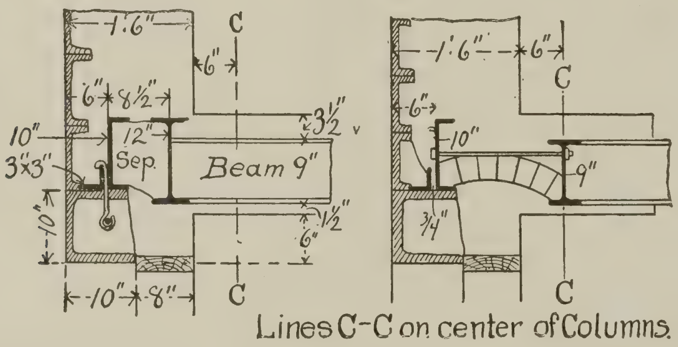


Fig. 216.

have been supported in several buildings, and with slight variations one or another of these methods can be adapted to almost any building.

It is probably hardly necessary to say that the metal work in this class of buildings should be very carefully designed and studied to suit the conditions of the building, and to provide ample strength, as well as arranged so that it may be fully protected from heat. Consideration must also be given to the effects of expansion and contraction in the frame.

327. Spandrel Supports.—The simplest case of spandrel supports is where the wall is perfectly plain and built of brick, with terra cotta caps and sills. In such cases a channel and angle bar may be used to support the outer face of the wall and an I-beam the

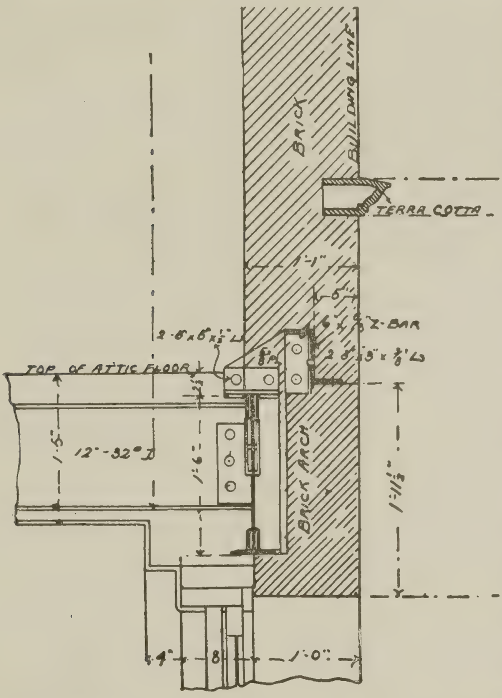
backing, as shown in Fig. 216, which shows sections of the outer walls of the Champlain Building, Chicago.*

The channel and I-beam should be bolted together with cast separators made to fit.

For a plain wall, channels and angles seem to be the best shape for the outer portion of the spandrel support, as they are of an economical section, and, the flat face of the channel being outward, a 4-inch veneer of brick can be set in front of it without clipping the brick. The face of the channel is generally set 5 or 6 inches from the face of the wall, and 3x3 angles are used for supporting the outer 4 inches of wall. The outer edge of the angle should come within $2\frac{1}{4}$ inches of the face of the wall.

Spandrel supports very similar to those shown in Fig. 216 have been used in several Chicago buildings.

Z-bars have also been used in several buildings in place of the channel and angle, but are not generally considered quite as satisfactory, as they do not give the same strength for the weight of metal used.



SECTION THROUGH ATTIC

Fig. 217.

Fig. 217 shows a Z-bar support used for the attic wall of the Wyandotte Building, Columbus, Ohio.†

Fig. 218, from the New York Life Building, Chicago, shows the spandrel supported by a single I-beam, the 4-inch facing of the wall being supported by the terra cotta lintel which is hung from the beam.

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* Holabird & Roche, architects.

† D. H. Burnham & Co., architects.

In the Reliance Building* plate girders were used for the main spandrel supports, and two angles riveted together to make a T were bracketed from the outer face of the girder to support the wall, the girder being on the centre line of the columns.

Fig. 219 shows the method used for supporting the granite walls at the fourth floor level of the Masonic Temple, Chicago. It should be noticed that an open joint is left opposite the supporting angle to allow for expansion and contraction in the column.

When the wall is faced with ornamental terra cotta the latter can seldom be supported directly by the spandrel beams, and a system of anchors must be resorted to, to properly tie the individual blocks either to the brick backing or to the metal work. These anchors are usually made of $\frac{1}{4}$-inch square or round iron rods, which are hooked into the ribs provided in the terra cotta blocks, and then drawn tight to the brickwork or metal work by means of nuts and screw ends, as shown in Fig. 221.

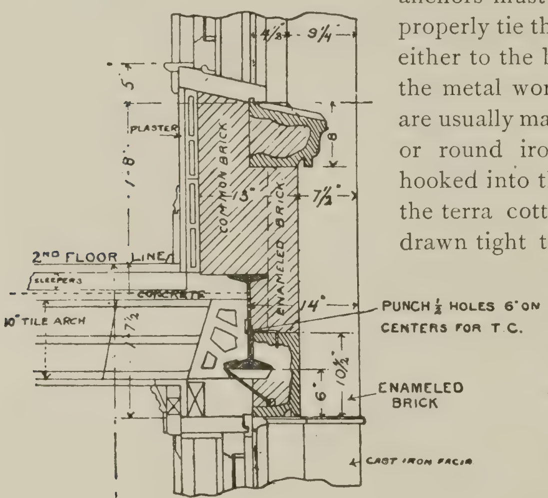

Fig. 218.

Hook bolts are largely used for tying terra cotta blocks to the metal work, the ends being bent around the bottom of the beams, channels or angles. Several examples of the use of hook bolts are shown in Figs. 218, 220, 221 and 222.

A great variety of methods for properly securing the terra cotta are possible. They should be carefully studied and the general scheme should always be indicated on the spandrel sections, in the manner shown in the illustrations, as the holes in the structural metal work necessary to receive the anchors should be shown on the detail drawings of the iron and steel work, so that the punching may be done at the shop. The inexperienced architect should also consult with

* D. H. Burnham & Co., architects.

the manufacturers of the terra cotta work as to the best manner of securing the blocks.

The anchorage of the brick and terra cotta to the steel frame is a matter of vital importance, as very serious consequences are quite sure to follow any neglect in this matter. "An instance is known where a whole section of wall facing on the court side of a high building fell off because the workmen omitted the anchors." As all the anchors for every block cannot be exactly shown on the drawings, either the architect or some one in his employ should give this portion of the work the strictest superintendence.

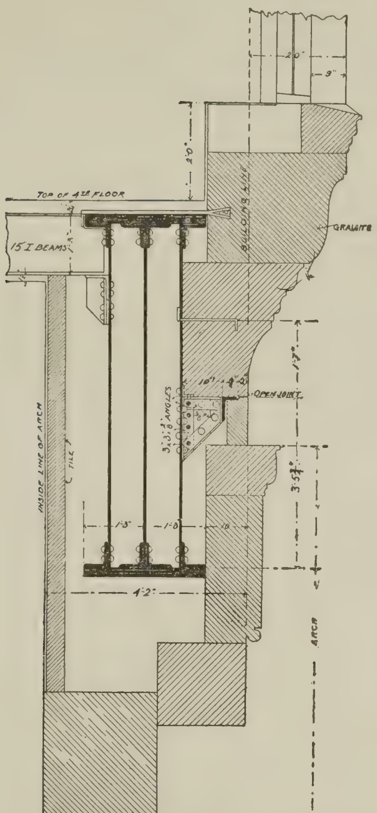

Fig. 219.

328. Bay Windows.—These have become a very prominent feature in the modern office building and hotel. In skeleton buildings the mason work of the bays is made as light as possible, with slight terra cotta mullions and angles, and is supported in each story by brackets built out from the spandrel beams or girders, as shown in Figs. 221 and 222, which are sections from the Wyandotte Building.

As the leverage on these brackets is considerable, they should be securely riveted to the spandrel beam, and the latter well tied or framed to the floor construction to keep it from twisting.

Where mullions occur between windows, and at the angles of the bays, cast iron or steel angle or T-bars are bolted or riveted to the metal work above and below, to stay the frames and terra cotta mullions and angles, in the manner shown in Fig. 223.

The importance of thoroughly fireproofing the exterior columns

has already been considered in Chapter IX. Fig. 223, however, is given as an example of the pier construction in Chicago buildings.

Further illustrations of the manner of supporting the mason work in this class of buildings may be found in *Architectural Engineering*, by Joseph K. Freitag, C. E., and several numbers of the *Engineering Record* and the *Brickbuilder*.

329. Miscellaneous Ironwork.—The following details of iron-work used in connection with brickwork and stonework should per-

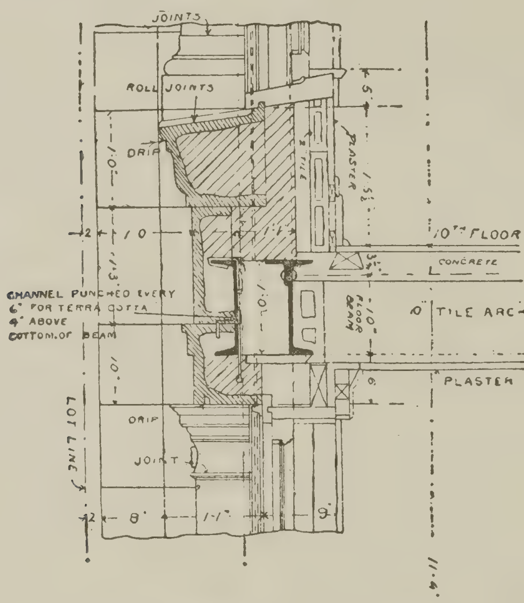

Fig. 220.—Section New York Life Building

haps be mentioned here, as they have to be considered when designing the mason work.

Bearing Plates.—Wherever iron or wooden posts, columns or girders rest on brickwork, a cast iron or stone bearing plate should be used to distribute the concentrated weight over a safe area of the mason work. Several failures in buildings have resulted from carelessness in this particular. Rules for proportioning the size of bearing plates are given in the *Architects' and Builders' Pocket Book.*

Cast Iron Skewbacks for Brick Arches.—Wherever segmental arches are used over doors or windows, without ample abutments,

cast iron skewbacks, connected by iron rods of proper size, should be used to take up the thrust of the arch, as shown in Fig. 224.

Shutter Eyes.—All fireproof doors and shutters in brick or stone walls should have hinges made of 2x¾-inch flat iron bars, welded around a ¾-inch diameter pin working in a cast iron shutter eye built into the wall. For brick walls the shape shown at *a*, Fig. 225,

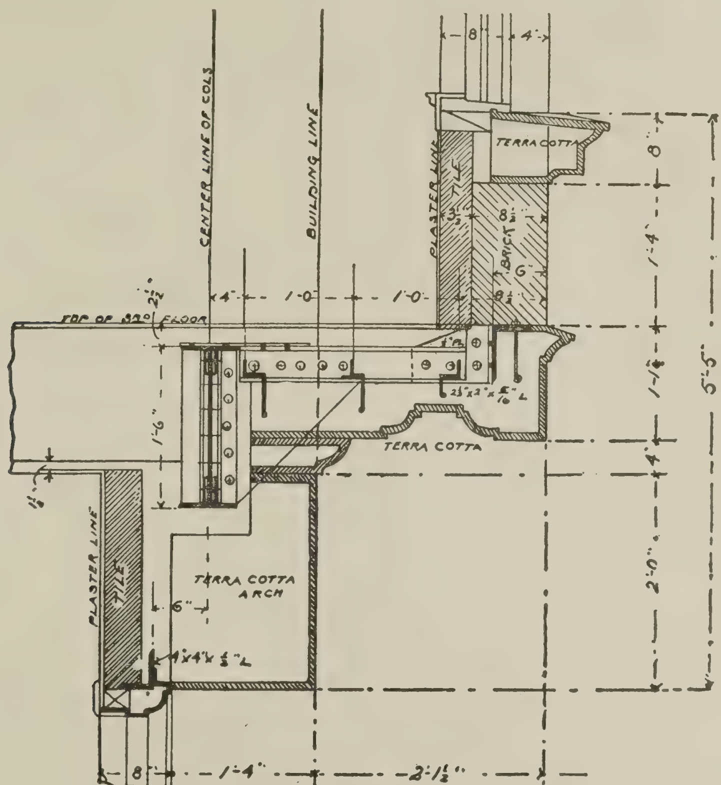

Fig. 221.

is about the best for the eyes, although for very heavy doors or shutters the strength of the face should be increased by having another web. For stone walls the shape shown at *b* should be used. The thickness of the metal is generally made ¼ of an inch.

Door Guards and Bumpers.—It is a good idea to protect the brick jambs of the carriage doors in stables by bumpers, which are rounded projections on the corners extending 12 to 18 inches above the ground

and about 8 inches beyond the wall and jamb, so that if the carriage wheel strikes the bumper the hub will not scratch the brick jamb. Such bumpers may be made either of some hard stone or of iron.

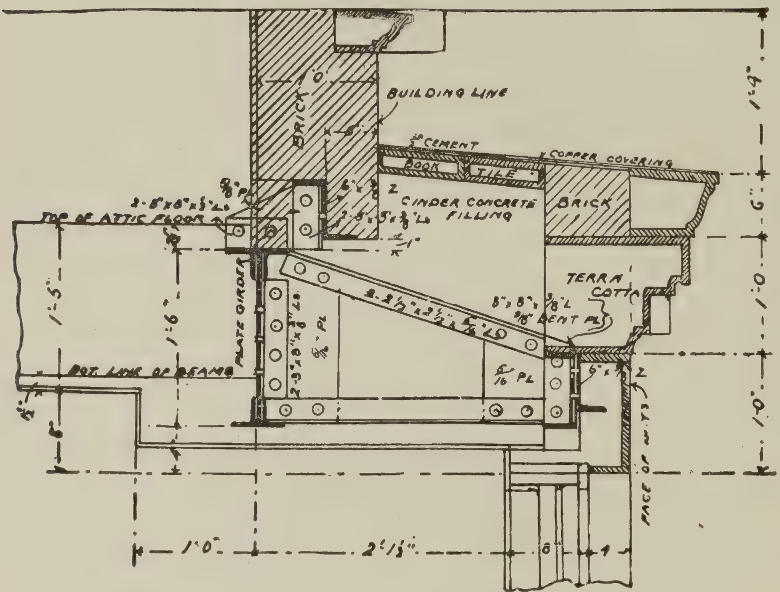

Fig. 222.—Section Through Top of Bays.

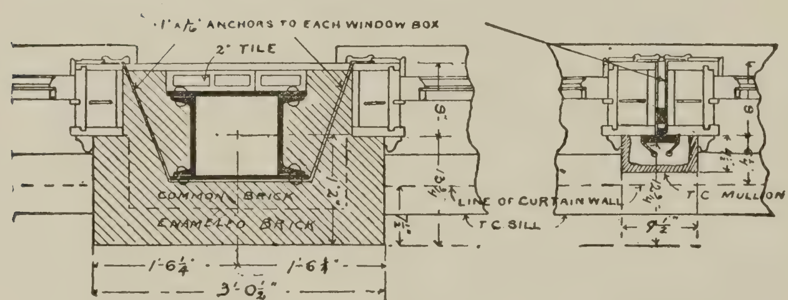

Fig. 223 —Plan of Piers and Mullions in Alley and Light Court, New York Life Building, Chicago.

The jambs of the exterior doors to freight elevators and of the delivery and receiving doorways in mercantile buildings should also be protected for a height of 4 or 5 feet above the sill by iron guards, to

prevent the brickwork being broken by boxes, trucks, etc. Such guards are generally made of cast iron about ½ inch thick, as castings can more easily be fastened to the wall than plate iron. The

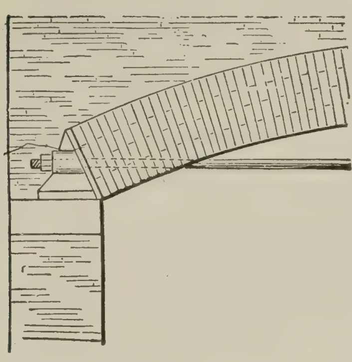

Fig. 224.

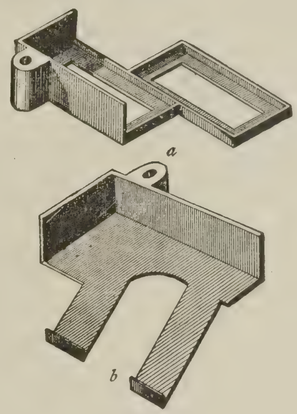

Fig. 225.

castings, or plates, should be made with lugs on the inside pierced with holes for clamping them securely to the brickwork as the wall is built. Fig. 226 shows a section of one of the alley piers of the New

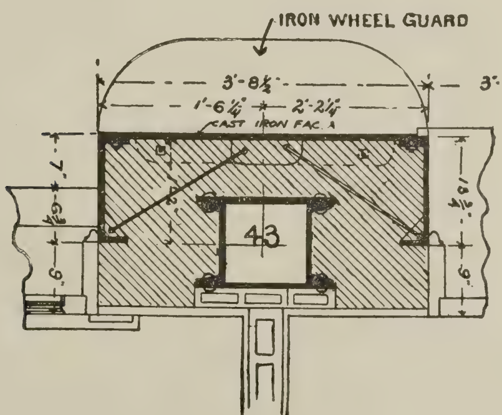

Fig 226.

York Life Building, Chicago, and the manner in which the iron guards are attached to the brickwork. A similar arrangement can be adapted to any door jamb. In Chicago it is quite common to protect

the bottoms of the piers on the alleys in this way to prevent injury to the walls from passing teams.

330. Chimney Caps.—For tall chimneys a cast iron cap is generally considered the most durable finish for the top. The usual shape of such caps is that shown in Fig. 227. Such a cap completely protects the mortar joints from the weather and prevents the bricks in the upper courses from becoming loose. If the chimney is corbeled out as shown the cap also acts as a drip to protect the sides of the chimney, at least near the top. The inner lip of the cap should extend down into the chimney from 8 to 12 inches. If the cap is not larger than 4 feet square it need be but $\frac{1}{4}$ of an inch thick; if larger than this the thickness should be increased to $\frac{3}{8}$ inch.

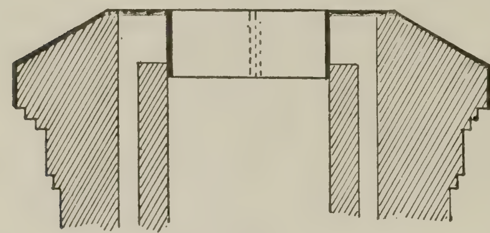

Fig. 227.

If the cap is 3 feet square or greater, for convenience in handling and casting it should be made in two or four sections, which should be bolted together, flanges being cast on the under side for this purpose.

Chimney Ladders.—It is sometimes desirable to have a ladder built inside of large brick flues, or shafts, and on the outside of tall chimneys to serve as a ready means of reaching the top. Such ladders are usually made of $\frac{3}{4}$-inch round iron bars, bent to the shape shown in Fig. 228 and placed in the wall of the chimney, or flue, when built. For easy climbing the rungs should be placed 12 inches apart between centres, and should be about 18 inches wide and project 6 inches from the wall.

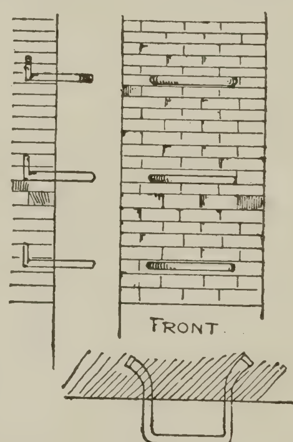

Fig 228.

Coal Hole Covers and Frames.—When coal vaults are placed under the sidewalk the architect should specify iron frames and covers for the holes made for putting in the coal. If the vault is covered with granite flagging a rebate may be cut in the stone to receive the cover,

and no frame is necessary. In all other stones, and in cement walks, the hole should be protected by a cast iron frame at least 4 inches deep. The frame is generally cast with a projecting ring about 2 inches wide and ½ inch thick, which should set in a rebate cut in the stone and filled with soft Portland cement. The frame is also made with a ¾-inch rebate for the iron cover. The cover is made of cast iron about ½ inch thick and should have a roughened surface on top. The covers are sometimes made with holes, into which glass bull's eyes are cemented to admit light to the vault. Both solid and glazed covers are generally carried in stock by the larger iron foundries, and in sizes from 16 to 24 inches in diameter.

Chapter XI.

LATHING AND PLASTERING.

331. Probably 99 per cent. of modern buildings, in this country at least, have plastered walls, ceilings and partitions. It is only lately, however, that much attention has been given to this branch of building operations, and there is probably no doubt but that much of the plastering done at the present day is inferior to that done fifty or one hundred years ago.

The introduction of fireproof construction and the desirability of completing large and costly business buildings in the shortest possible time has shown the necessity for improvements in the materials used both for the lathing and the plastering, and several new materials have been introduced to meet the demand.

Even in dwellings it is important that the finish of the walls and ceilings shall be as nearly perfect as possible, as large sums of money are not infrequently spent on their decoration, and it is therefore essential that the ground work shall be so durable that the decorations will not be ruined by broken walls or falling ceilings. The quality of the workmanship is also of much importance, as nothing mars the appearance of a room more than crooked walls and angles, and dents, cracks and patches in the plastering.

To secure a good job of lathing and plastering it is essential that only the best materials be specified and used, and that the mortar be properly prepared and applied. These can only be insured by being careful to specify exactly how the work shall be done and the materials that shall be used, and supplementing the specifications by efficient supervision. In order to furnish such specifications and superintendence, it is obviously necessary that the architect shall be thoroughly familiar with the materials used and the way in which they should be applied.

LATHING.

332. Brick walls and hollow tile ceilings and partititions do not require lathing, as the plastering may be applied to them directly, the brick and tiles having an affinity for the mortar which holds it

securely in place. All other constructions require some form of lathing to serve as a ground to receive and hold the plaster.

Wooden Laths.—Practically all dwellings of moderate cost, and a large proportion of other buildings, are still lathed with wooden laths, and if of good quality they give very satisfactory results where no fireproof quality is expected. It is generally admitted that the best wood for laths is white pine, although nearly as many are made of spruce, which answers very well. Hard pine is not a good material for laths, as it contains too much pitch.

Wooden laths should be well seasoned and free from sap, bark and dead knots. Small sound knots are not particularly objectionable. *Bark* is often found on the edges of laths, and is probably the greatest defect that they are subject to, as it is quite sure to stain through the plaster.

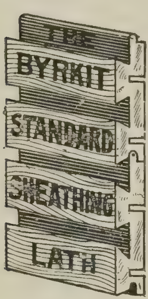

Fig. 229.

The usual dimensions of wooden laths are ¼ x 1¼ inches in section and 4 feet long; the width and thickness vary somewhat in different mills, but the length is always the same. The studding or furring strips should therefore be spaced either 12 or 16 inches apart from centres; 12-inch spacing gives five nailings to the lath, and 16-inch spacing four nailings.

The former obviously makes the stronger and better wall. It is particularly desirable that laths on ceilings have five nailings, as there is more strain on them than on those on the walls.

Sheathing Lath.—A combination sheathing and lath, known as the Byrkit-Hall Sheathing Lath, has been on the market for 15 years, and is highly endorsed by Architects for the purposes intended. It is made by special machinery from pine, hemlock, cypress, and poplar, in same lengths as flooring and in 4 and 6 inch widths, the edges being both tongued and grooved and square. The general principle of the lath is shown by Fig. 229, a full-size section and more complete description being given in section 143 of Part II.

When used on the outside of frame walls, it answers the purpose of sheathing, and also forms a clinch for back plastering on the inside.

For Stucco buildings, staff, plaster of paris ornamentations, and imitations of stone, the grooved side can be placed out to receive the mortar.

Thirty million feet of this lath were used on the Columbian Exposition Buildings in 1892 and 1893; Twelve million feet on the Pan American Exposition Buildings and about thirty million feet will be

used at St. Louis, Missouri Over eighty five million feet of the Byrkit Lath are now used annually in the United States. In the North, Northwest and middle States, this lath has been extensively used for rough cast, back plastering and interior lathing.

333. Metal Laths.—*Wire Cloth.*—About eighteen years ago when the interest in fireproof construction became more general, wire netting came into use as a substitute for the wood lath. It was found that the strands of the netting became completely imbedded in the plaster and held it so securely that it could not become detached by any ordinary accidents. The plaster also protects the wire from the heat, and the body of the metal is so small that there is no appreciable expansion of the metal when subjected to fire.

The author believes that heavy wire cloth tightly stretched over metal furrings forms the most fireproof lath now on the market, and he has personally seen it demonstrated by severe experimental tests, and by actual fires in buildings, that plaster on wire cloth, and particularly hard plasters, will protect the woodwork from a severe fire so long as the plaster remains intact, *provided* there are no cracks or loopholes at the corners and around columns where the fire can get through.

The objection has been found to the ordinary wire lath that it is difficult to stretch it so tight that it will not yield to the pressure exerted in applying the several coats. Another objection that is made to the wire lath, and also to the expanded lath (Fig. 231), is that they take a great deal of plaster. From the standpoint of *first cost* this is undoubtedly a valid objection, but from a fireproof standpoint the great amount of mortar used is its principal value. It should be remembered that the *mortar* is the *fireproof* part of the wall or ceiling, and *not* the metal. No metallic lath, the author believes, should be considered as fireproof which does not, in use, *become imbedded in the mortar*, for if the thin coating of plaster peels off the metal lath will resist the fire no better than the wood lath, and will be more in the way of the fireman.

Wire lathing is now made in great variety to meet the requirements of the different plastering compositions and the varying conditions of construction.

Plain lathing is plain* wire cloth, usually $2\frac{1}{2}$x$2\frac{1}{2}$ meshes to the inch, made from No. 17 to No. 20 wire. No. 20 is more generally used than any other size.

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* The word plain is here used to designate ordinary wire cloth, without corrugations or stiffening bars. As used by the trade the word "plain" means lathing that is not painted or galvanized.

The lathing is also sold plain, painted and galvanized. Painted or galvanized lathing should be used in connection with special hard plaster compounds. Painted lathing costs about one cent per square yard more than "bright" lathing.

Galvanizing the wire cloth after it is woven adds very much to its stiffness, as the zinc solders the wires together where they cross. Galvanized lathing is also less liable to corrosion before the plastering is applied than the plain lathing.

The usual widths of wire lathing are 32 and 36 inches, although the Roebling lath may be obtained of any width up to 8 feet.

All wire lathing should be stretched tight when applied, so as to insure a firm surface for plastering. For this purpose stretchers are supplied by the manufacturers.

Furring for Wire Lath.—In order to properly protect wooden construction, such as beams, posts, studding or plank, from fire, by wire lath and plaster, it is essential that the lath be kept at least $\frac{3}{8}$ inch away from the woodwork by iron furring of some form, and a 1-inch space is much better. This setting off of the lath from the wood is generally done either by means of bars woven into or attached to the lathing, or by means of iron furring put up before the lathing. Probably the most common method of furring with iron for wire lath has been by means of band iron, either straight or corrugated, $\frac{1}{2}$ inch or $\frac{3}{4}$ inch wide, set on edge and secured to the under side of the joist or plank by narrow staples, driven so as to keep the iron in a vertical position.

On floor beams and studding, unless heavy iron is used, it is necessary to run the furring lengthways of the beams and studding, and, as the latter are seldom less than 12 inches on centres, this does not give close enough bearings to secure a stiff surface for the plastering.

Under plank (mill) floors the band iron should be spaced every 8 inches, and, if corrugated iron is used, a very satisfactory surface is obtained. After the furring is fixed in place the cloth is then stretched over it and secured by staples nailed over the wire and the band iron.

*Hammond's Metal Furring.**—A much better system of furring, and, so far as the author is informed, the most perfect of all systems of *separate* furring over woodwork, is that known as the "Hammond" furring, and shown by Fig. 230. It consists of a combination of sheet metal bearings and steel rods. The rods form the furring for keeping the wire cloth away from the timber, and the bearings form the offset for the rods, both being secured to the joist, studding or plank by means of staples, as shown in the figure. The rods, being only about $\frac{1}{8}$ inch

* Controlled by the Gilbert & Bennett Manufacturing Co.

in diameter, become completely imbedded in the plaster when it is applied, and as the plaster hardens it unites the rod and cloth so as to make a much more rigid surface than is possible where band iron furring is used. The rods also may, and in fact should be, run across the beams or studding, and may therefore be spaced as close together as desired. It is recommended that the spacing of the rods be made $7\frac{1}{5}$ inches where the joist are 12 inches on centres and 6 inches when the joist are 16 inches on centres (being 5 and 6 bars to each strip of lathing). The bearings are $\frac{1}{2}$ inch and 1 inch deep, the latter being recommended, as they give a greater air space between the plaster and timber, which is especially desirable in lathing around solid timbers or under planking. The rods come in lengths of about 10 feet.

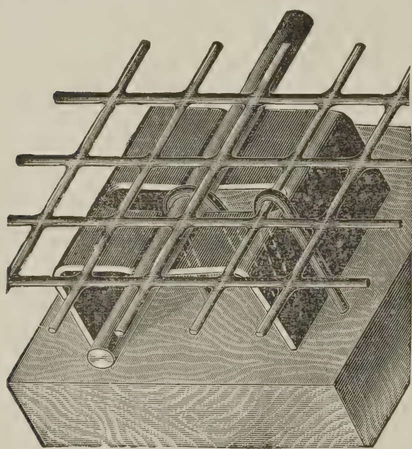

Fig. 230.

This system of furring is applicable to wooden posts, partitions and any form of wood construction; it is readily put up, and is but little more expensive than band iron. After the furring is in place the wire cloth (which should be No. 20 gauge, and painted or galvanized if hard plasters are to be used) is stretched over it, preferably in the same direction as the rods, and secured by staples driven over the wire and one side of the bearing, as shown in the figure.

Corrugated Wire Lathing.—A lathing made of flat sheets of double twist warp lath, with corrugations $\frac{3}{8}$ of an inch deep running lengthwise of the sheet at intervals of 6 inches, has been used to some extent. The sheets are made 8x3 feet in size and applied directly to the under side of the floor timbers, to partitions or to brick walls, and fastened with staples. The corrugations afford space for the mortar to clinch behind the lath, and thus do away with the necessity for furring strips; they also strengthen the lathing.

Stiffened Wire Lathing.—In order to avoid the labor and expense of furring with metal, wire lathing having the furring strips attached to the fabric was introduced some years ago, and has been very extensively used, and the author would recommend that whenever

wire lathing is used over wood construction that either one of the stiffened wire laths, or ordinary wire cloth with the Hammond furring, be specified.

Two varieties of stiffened wire lathing are now on the market. Each has been extensively used, with satisfactory results.

The Clinton stiffened lath has corrugated steel furring strips attached every 8 inches crosswise of the fabric by means of metal clips. These strips constitute the furring, and the lath is applied directly to the under side of the floor joist, or to planking, furring, brick walls, etc. This lath is made in 32-inch and 36-inch widths and comes in 100-yard rolls.

The Roebling stiffened lathing, made by the New Jersey Wire Cloth Co., is made of plain wire cloth, in which, at intervals of $7\frac{1}{2}$ inches, stiffening ribs are woven. These ribs have a V-shaped section and are made of No. 24 sheet iron, and vary from $\frac{3}{8}$ to $1\frac{1}{2}$ inches in depth. The $\frac{3}{8}$-inch rib is the standard size for lathing on woodwork. This lathing requires no furring, and is applied directly to woodwork or walls with steel nails driven through the bottom of the V, as shown in Fig. 230 A.

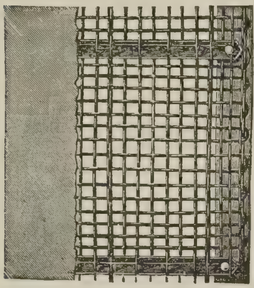
Fig. 230 A.

The No. 20 V-rib stiffened lathing affords a satisfactory surface for plastering, when attached to studs or beams spaced 16 inches apart. The lathing should be applied so that the widths will join on a beam or stud.

The $1\frac{1}{4}$-inch V-rib lathing is used for furring exterior walls. It provides an air space between the wall and plaster.

For iron construction a $\frac{1}{4}$-inch solid steel rod is substituted for the V-rib, and the lathing is attached to light iron furring with lacing wire.

The Roebling lath is made with $2\frac{1}{2}$x$2\frac{1}{2}$, 3x3 and 3x5 mesh, the latter being known as "close-warp." The $2\frac{1}{2}$x$2\frac{1}{2}$ mesh should be used for ordinary lime and hair mortar, and the 3x3 or 3x5 mesh for hard plasters and thin partitions. This lathing is also sold bright, painted and galvanized.

The No. 20 painted wire has been extensively used, and much of it has been in service for from 6 to 8 years and is now apparently as good and strong as ever, so that there appears to be no necessity in ordinary work of using heavier wire or galvanized netting.

The galvanized wire is stiffer than the painted, and would possibly wear longer, but it is doubtful if the advantages are at all proportionate with the cost.

334. Expanded Metal Lath.—This lath (Fig. 231), now probably well known to architects, is made from strips of thin, soft and tough steel by a mechanical process which pushes out or expands the metal into oblong meshes, and at the same time reverses the direction of the edge, so that the flat surface of the cut strand is at right angles with the general surface of the sheet.

Two sizes of meshes are made, $\frac{3}{16}$x$1\frac{1}{4}$ inches and $\frac{1}{4}$x$1\frac{1}{4}$ inches, the former being best adapted for the hard mortars and the latter for lime mortar. Both kinds are made in sheets 8 feet long and from 14 to 20 inches in width, 18 inches being the standard width.

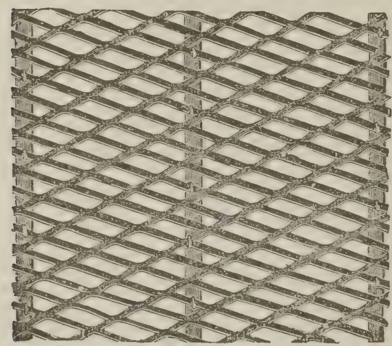

Fig. 231.

This lath being flat and of considerable stiffness does not require to be stretched, and can be fastened directly to the under side of floor joist or to wood studding. If used on plank it should be fastened over metal furring strips. When applied to studding the lath should be placed so that the long way of the mesh will be at right angles to the studding, as shown in Fig. 231, as this insures the greatest rigidity. The studding or furring strips should be spaced 12 inches on centres and the lathing secured with staples 1 inch long, driven about 5 inches apart on the stud or joist. The lath, when applied, is a scant $\frac{1}{4}$ inch thick, and to obtain a good wall $\frac{1}{2}$-inch grounds should be used.

There are several companies manufacturing this lathing under territorial rights, and it has been extensively used with very satisfactory results. The author believes it to be the most fireproof lath made from sheet metal.

335. Perforated Sheet Metal Laths.—There are some six or more styles of metal lath made from sheet iron or steel by perforating the sheets so as to give a clinch to the mortar. The sheets are generally corrugated or ribbed, also, in order to stiffen them and keep them away from the wood. There is not a great difference between

these laths, although some styles may possess certain advantages over the others.

In general, the author would prefer those styles which have the greatest amount of perforations, or which approach the nearest to the expanded lath. All of these laths come in flat sheets about 8 feet long and 15 to 24 inches in width, and are readily applied to woodwork by means of barbed wire nails. The nails should be driven every 3 inches in each bearing, commencing at the centre of the sheet and working toward the ends. These lath work very nicely in forming round corners and coves, and are generally preferred to the wire lath by plasterers, as they are easier to put on. They are certainly much superior to wood laths. Metal lath should never be cut at the angles of a room, but bent to the shape of the angle and continued to the next stud beyond. This strengthens the wall and prevents cracks at the angles.

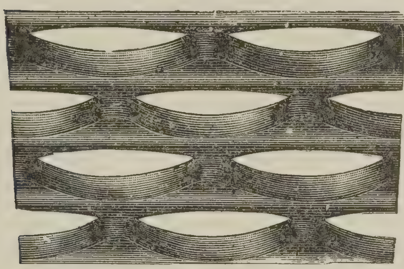
Fig. 231 A.

Of the various forms of sheet metal lath in common use, the Bostwick lath (Fig. 231 A) is perhaps the best known and most extensively used. It is made of sheet steel, with ribs every $\frac{3}{4}$ of an inch in the width of the sheet, and loops, $\frac{3}{8}$x$1\frac{3}{4}$ inches, punched out between the ribs; the lath should be applied with the loop side out. This lath can be put on as fast as the wood lath, and is especially well adapted to round corners and coves.

Picture mouldings should always be placed around all rooms lathed with metal lath, although screws can be quite readily secured in the lath by first making a small hole with a punch or drill.

When using common lime mortar on metal lath the first coat should be gauged with plaster of Paris. Either painted, galvanized or japanned lath should always be used for hard plasters made by a chemical process, such as King's Windsor and adamant.

Aside from their fireproof qualities, wire or metal laths possess the advantages that plastering applied to them will not crack from shrinkage in the woodwork, nor can the plaster fall off. If the lathing is set away from the wood studding, the location of the timbers will not be shown by the plaster, as is invariably the case after a few years when wood laths are used. Metal laths are also proof against

rats and mice, which makes them especially desirable in certain kinds of store buildings. Nearly all these advantages are lost when unstiffened wire cloth is stretched over wood furrings.

336. Plaster Boards.—Thin boards made of plaster, and reeds or fibre, have also been quite extensively used, not exactly as a lath, but as a ground for the second and third coats of plaster. They are made in slabs about $\frac{5}{8}$ inch thick, 16 inches wide and 4 feet long. The Mackite boards are made $\frac{3}{4}$ inch and 1 inch thick for ordinary work. The under surface of the boards should be grooved or left rough to receive the plastering.

The materials of which the boards are made consist chiefly of plaster of Paris and some sort of fibre. The Mackite boards also have hollow reeds imbedded in them. The boards can be sawed into any size or shape and nailed directly to the under side of the joist, or to studding or furring. They are rapidly put on and require no scratch coat, and with some styles of boards a white or finished coat is all that is necessary.

Actual fire tests appear to show that fire does not harm the plaster board more than the terra cotta tile, and on account of their lightness, and the ease with which they can be cut, they are sometimes preferred to tile or terra cotta for suspended ceilings under iron beams.

Owing to the saving of plaster, the low cost of the boards and the ease with which they are put up, plaster boards probably offer the cheapest fireproof ceiling yet devised.

In using plaster boards, or any of the patented laths, the architect or builder should follow the directions of the manufacturers as to the manner of putting up, etc., as there are often important precautions which might otherwise be overlooked.

337. Where Metal Lathing Should be Used.—It is of course desirable that metal lathing or plaster boards should be used wherever any lathing is required, but the increased expense generally prevents their use in the majority of buildings.

There are, however, many places where it is particularly desirable, especially in buildings having ordinary wood floors and partitions. Such places are the under side of stairs in public buildings, the ceilings in audience and assembly rooms, under side of galleries, ceilings of boiler and furnace rooms, etc.

Metal lathing should also be used on wood partitions, on both sides of hot air pipes. Where there are slots in brick walls for plumbing, hot air or steam pipes, they should be covered with metal lath, unless the walls are furred or the recesses cased with boards.

Metal lath should also be used at the junction of wood partitions and brick walls, when the walls are not furred, and particularly when the partition is parallel and flush with the wall.

By using a strip of wire cloth or expanded metal, lapped 12 inches on the wall and partition, a crack at the juncture of the two will be avoided, and at only a very slight additional expense.

It very often happens in outside brick walls that the arched wooden lintels over the windows come partly above the casing, and if the wall is plastered directly onto the brick the plastering generally cracks over, or will not stick to the lintel. This can be avoided by covering the lintel with a strip of metal lath, lapped 6 or more inches on the brickwork.

In general, wherever solid timber has to be plastered, without room for furring and lathing, it should be covered with metal lath, which should also be lapped well on to the adjoining partition or wall.

PLASTERING.

338. Interior Work.—The very general practice of plastering walls and ceilings dates back not much more than a century ago. Previous to that time the walls and ceilings were either wainscoted, boarded, or covered with canvas or tapestries, or else left rough.

On account of its cheapness, its fireproof and deafening qualities, and its adaptability to decorative treatment, some kind of plastering will probably always be used for finishing the interior walls and ceilings of buildings.

In describing plastering operations, it will be more convenient to divide the subject under the heads of Lime Plaster, Hard or Cement Plaster, Stucco Work and Exterior Plastering.

Lime Plaster.—*Materials.*—*Lime.*—Until within about ten years all interior plastering used in this country was made of quicklime, sand and hair.

There can be no question but that plaster made of a good quality of lime, thoroughly slaked and mixed in the proper manner, is very durable and also a valuable sanitary agent. Most of the lime plaster used at the present day, however, is very poorly and cheaply made, often of poor materials, and very much of it is far from durable.

The stones from which lime is made, and the method of preparing it for the market, are described in Sections 100 and 154.

Materials for making lime are found in nearly every State in the Union, but as no two quarries of stone are exactly alike, there is a

great difference in the quality of limes from different stones. In some localities, also, lime is obtained from shells and marble.

The manner of working the lime also varies in different localities.

In New England and New York lime is generally put up in casks or barrels and sold by measure, but in many of the Western States it is sold loose, like coal, and by weight.

There are some limes which, while good enough for making ordinary mortar, are not suitable for making plaster; this is because all the particles of the lime do not immediately slake. Some of the particles, because they are over-burned or for some other reason, will not slake with the bulk of the lime, but continue to absorb moisture, and finally after a long period, extending sometimes over two years, they will slake or "pop" and cause a speck of plaster to fall off.

The author has seen walls and ceilings that were pitted all over from this cause.

It is therefore important that the architect, when building in a new locality, or upon commencing his practice, should make inquiries as to the slaking qualities of the lime at hand, and where more than one lime is available, which one is the best. In some localities four or five different qualities of lime, from as many different places, are found on the market, and in such cases the architect should be very careful to specify the particular lime which he considers best. [Limes are generally known by the name of the locality where they are quarried.] Even in the best limes some particles do not slake quite as quickly as others, and it is not generally safe to apply any plastering in which the lime has not been slaked from ten days to two weeks.

Sand, for plastering, should be angular, not too coarse nor too fine, and free from dust and all foreign substances. Methods of testing sand for foreign substances were described in Section 103.

To make the very best plaster, the sand should be *screened*, *washed* and *dried;* sand prepared in this way can sometimes be obtained in the larger cities, but in most work the sand is merely screened.

Of unprepared sand, river sand is generally the best, as it is less likely to contain impurities. Pit sand is very apt to contain clay.

Sea sand is less angular than other sands, and is also considered objectionable on account of the salt contained in it. It should never be used without thorough washing in fresh water. All sands require careful screening to take out the coarse particles, and sand for hard finish should be passed through a sieve.

Although the use of sand in mortar is principally to prevent shrink-

ing and reduce the quantity of lime, it is also considered to have a valuable chemical function, causing the formation of a hard silicate of lime, which pervades and strengthens the plaster.

Hair and Fibre.—To make the coarse plaster hang together better, hair or fibre should be mixed with the mortar for the ground work.

Outside of a few of the large Eastern cities hair is almost entirely used for this purpose. For several years Manilla fibre, chopped about 2 inches long, has been used instead of hair for ordinary mortar in New York City and vicinity. Most of the patent mortars contain either asbestos or Manilla fibre. Fibre is cleaner than hair, and is said to be less injured by the lime.

Most of the hair used by plasterers is taken from the hides of cattle, and is washed and dried and put up in paper bags, each bag being supposed to contain one bushel of hair after it is beat up.

The weight is generally given as 7 or 8 pounds, but it often falls much short of this.

If obtained from a local tannery, the hair should be thoroughly washed and separated before using.

Hair is generally described in the specifications as "best quality of clean, long cattle hair," but the plaster must take it as it comes in the bags.

Goat hair is used to some extent in the Eastern States. It is longer and of a better quality than cattle hair.

339. **Mixing Mortar for Plastering.**—The proper mixing of lime mortar is nearly as important as the quality of the lime. The tendency to reduce the cost of building to the lowest possible point, and to shorten the time required for the various operations, has, with other influences, led to much neglect in the mixing of mortar, and it is safe to say that three-quarters of the lime plaster used at the present time is not properly mixed.

Where mortar is mixed by hand at the site of the building, the following method is probably the best that can be considered as practicable :

First the lime should be thoroughly slaked in a tight box, or, if the lime is not pure, so that a residue is left after slaking, it should be run off through a wire sieve into another box and allowed to stand for from twenty-four hours to seven days.

Second. After the lime has been slaked the required length of time the hair should be beat up and thoroughly incorporated with the lime paste with a hoe, and the proper amount of sand then added and the mixture thrown into a pile.

Third. After the mortar has stood in the pile not less than seven days, it should be wet up with water to the proper consistency in small quantities and immediately applied to the lathing or brickwork.

The ordinary method of mixing plastering mortar is to mix the hair and sand with the lime as soon as it is slaked, and then throw the mortar into a pile, the whole process occupying but one or two hours. The objection to this method is that the lime does not always get thoroughly slaked, and the hot lime and the steam caused by the slaking burn or rot the hair so as almost to destroy its function of strengthening the plaster. For all good work the architect should specify that the lime be slaked at least twenty-four hours before working in the hair.

For U. S. Government work the hair is not mixed in until the mortar is wet up for putting on, which is still better, but rather more expensive.

If the mortar is required in freezing weather it should be made under cover, and under no circumstances should the architect permit the use of mortar that has been frozen.

The mixing of mortar in basements, although sometimes found necessary, is not desirable, as it introduces much moisture into the building. Mortar should never be made in the building when practicable to avoid it.

340. **Machine-made Mortar.**—In New York City, Philadelphia, and possibly some other places, mortar, both for bricklaying and plastering, is now made by machinery in buildings specially arranged for the purpose, and delivered at the work in cart load lots in a wet and plastic condition, with the hair or fibre, and fresh water incorporated with the lime and sand, ready for use, without the addition of any other material or further manipulation whatever.

The advantages of having the mortar made in this way are that ample time is given the lime to slake, the hair and sand are not mixed with the lime until just before delivery, and the mixing is much more thoroughly and evenly done by machinery than is possible by hand.

Using mortar mixed at some other place than in the building permits of finishing the lower stories sooner than could otherwise be done, and also does away with the inconvenience of having a large pile of mortar stacked on the sidewalk or in the basement.

Machine-made mortar was used in the Corn Exchange, the Manhattan Life Building, the Home Life Insurance Building, and many other large buildings in New York.

The process of making the mortar in the Philadelphia plant is described as follows:

Into four slacking machines or revolving pans, about twelve bushels of lime are placed and enough water introduced to slack without burning. The pan is started and the lime is kept in motion by a mechanical arrangement consisting of three feet on a perpendicular shaft. When the slacking is complete a plug is removed, and the lime and water carried by a trough through three screens into a well; from this well it is pumped into vats located in the upper floors of the mixing house. Screening the lime eliminates all core or underburnt limestone, stones and other foreign matter so injurious to mortar, especially that used by plasterers.

When the lime and water is pumped into the vats it much resembles thick milk, which, after standing three weeks, assumes the consistency of soft cheese. Water is allowed to stand in these vats, which further aids in the slacking of any minute particles that have escaped through the sieves, and also to prevent the air from reaching it. (The lime used contains a considerable amount of magnesia, a pure carbonate not giving the setting qualities desirable.)

When mortar is to be made this lime paste is carried to the mixing pans, which are like those used in slacking, with the exception that they have two sets of feet; sharp, clean bar sand is also placed in the pans, and the machine thoroughly incorporates the lime and sand into a homogeneous mass, not a streak of lime and a streak of sand, but a material of uniform evenness. As a result of this care, I have tested brickquetts made of machine mortar and have obtained as great a tensile strain as 52 pounds to the square inch; in twenty-seven or twenty-eight days, out of three brickquetts broken, I secured 48, 52 and 50 pounds tensile strain. We never allow lime to air slack; neither do we mix the sand with the hot lime and allow it to stand.*

When mixing mortar by hand, the nearer the process approaches the above the better will be the quality of the plastering.

341. Proportion of Materials.—It has been found by repeated experiments that a barrel of Rockland lump lime, thoroughly slaked, will yield on an average 2.72 barrels of lime paste. Some limes will yield more and others less, the average of four Eastern limes tested being 2.62 barrels of paste. It has also been demonstrated by repeated experiments that the *average* sum of voids in sharp, clean, silicious bank or pit sand, taken from different locations and thoroughly screened, is .349 of its bulk. It was also shown that the *best* mortar is obtained by mixing with the sand such an amount of lime paste as will be from 45 to 50 per cent. greater than the amount needed to fill the voids of the sand, which practically requires a proportion of 1 part lime paste to 2 of sand. This is the proportion usually specified on Government work.

As it is difficult to measure the lime paste, it would perhaps be better to specify that only 5½ barrels of screened sand should be used

* Henry Longcope, in the *Brickbuilder*.

to one cask of lime. Where lime is sold by weight about the same proportions will be obtained by specifying $2\frac{1}{2}$ barrels of sand to 100 pounds of dry lime.

Mixed in the above proportions it will require about $2\frac{1}{2}$ casks, or 500 pounds, of lime and 14 barrels (42 cubic feet) of sand to cover 100 yards of lath work, $\frac{3}{8}$ inch thick over the lath.

The proportion of hair to lime should be for first-class work, $1\frac{1}{2}$ bushels of hair to one cask, or 200 pounds, of lime for the scratch coat, and $\frac{1}{2}$ bushel of hair to one cask of lime for the brown coat. This is considerably more, however, than will be found in most plaster.

The proportion of lime given above is none too rich for first-class plaster, either for the brown or scratch coat, but it is seldom, if ever, that brown mortar is made as rich as this, and much first-coat work is inferior to it.

In fact, it is almost impossible to regulate the proportion and uniform mixing of common plaster. Where lime is sold by the cask it can be done by mixing one cask of lime at a time and measuring the sand, but where lime is sold by weight it would be necessary to keep scales on the ground for weighing the lime; and in either case it would be necessary to have an inspector to watch the making of the mortar.

In practice the lime is slaked and as much sand mixed with it as the mortar mixer thinks best or the plaster will stand, and it is almost impossible for the architect to tell whether or not there is too much sand. It seldom happens that there is too little sand.

After considerable experience with mortar, one can tell something about its quality by its appearance when wet up, or by trying it with a trowel, but practically the architect and owner is in most cases at the mercy of the contractor, and about the best that can be done, when using common plaster, is to insist on the best materials, mixing in the hair after the lime is cool and giving the contract to an honest and intelligent plasterer.

342. Putting On.—Plastering on lathed work is generally done in three coats.* The first coat is called the *scratch* coat; the second the *brown* coat; and the third, the *white* coat, *skim* coat or finish.

On brick or stone work the scratch coat is generally omitted.

* In the Eastern States dwellings of moderate cost are generally plastered with two-coat work, the first or scratch coat being brought out nearly to the grounds, and carefully straightened to receive the skim coat.

The scratch coat should always be made "rich," and should contain plenty of hair or fibre, as it forms the foundation for the brown and white coats. This coat is generally put on from $\frac{3}{16}$ to $\frac{1}{4}$ inch thick over the laths, and should be pressed by the trowel with sufficient force to squeeze it between and behind the laths, so as to form a key or "clinch." It is this key which holds the plaster to the laths. When the first coat has commenced to harden (the time varying from two to four days) it should be scored or scratched nearly through its thickness with lines diagonally across each other, about 2 to 3 inches apart. This gives a better hold to the second coat.

The first coat should be thoroughly dry before putting on the second coat, but if the surface is too dry it should be slightly dampened with a sprinkler or brush as the second coat is put on.

A great deal of plastering (sometimes called "green work") is done where the brown coat is applied from the same stage, and as soon as the scratch coat is put on. When done in this way the scratch coat is generally made very rich and the brown coat largely of sand, the brown coat being worked into the scratch coat so that it really makes only one coat.

All intelligent plasterers admit that it makes *better work* to let the scratch coat get dry before the brown is put on, but as it takes more labor and also more lime to put on the plaster in this way, they will not do it unless it is particularly specified. Besides not giving as good a wall, applying the brown coat to the green scratch coat also causes the laths to swell badly, which, when they dry, causes cracks in the plastering.

The second or "brown" coat is put on from $\frac{1}{4}$ to $\frac{3}{8}$ inch thick. With this coat all the surfaces should be brought to a true plane, the angles made straight, the walls plumb and the ceilings level.

On the walls the plastering can generally be brought to a true plane by means of the grounds, if the latter are set true and the wall is not too large or without openings. On the ceilings, however, there is usually nothing to guide the plasterer in his work, and the consequence is that most ceilings, particularly in domestic work, have a *rolling* surface, as can be detected at the edges of the ceiling.

Screeds.—The only way of obtaining a true plane on ceilings and on walls, where the grounds are not sufficient, is by *screeding*, which is done by applying horizontal strips of plaster mortar, 6 to 8 inches wide and from 2 to 4 feet apart, all around the room. These are made to project from the first coat out to the intended face of the second coat, and while soft are made perfectly straight and out of

wind with each other by measuring with a plumb, straight-edge, etc. When dry the second coat is put on, filling up the broad horizontal spaces between them, and is readily brought to a perfectly flat surface corresponding with the screeds by long straight-edges extending over their surface.

On lathed work, if the studding or furrings have been properly set, screeding should not be necessary except on ceilings, but on brick or stone walls it is impossible to get true surfaces except by means of grounds or screeds. Screeding was formerly done much more extensively than at present; now it is seldom required except in very expensive buildings. Screeding can be done only in three-coat work. Before the brown coat becomes hard it should be lightly run over with the scratcher to make the third coat adhere better. If part of the walls are to be plastered on brickwork and part on laths, the scratch coat is put only on the laths, and when this is dry the brown coat is spread over the whole, including the brickwork. Brick walls that are to be plastered should have the joints left rough or open, and the walls should be brushed clean of all dust and slightly *dampened* before putting on the mortar. In very dry weather the brick walls should be sprinkled with a hose just before plastering.

343. Third or Finishing Coat.—The method of finishing the wall varies somewhat in different parts of the country, and also with the kind of surface desired. In some localities, particularly in small villages, when the walls are to be papered, no finishing coat is applied, but the brown or scratch coat is smoothly troweled. This reduces the expense but a trifle and is not to be recommended, as the walls cannot be as well straightened and the roughness of the plaster will show through the paper.

Skim Coat.—In many of the Eastern States the finishing coat is called the *skim coat*, and is made of lime putty and a fine white sand—generally washed beach sand. The lime is slaked and run through a sieve into a tight box, and there allowed to stand until it becomes of the consistency of putty, when it is taken out and the sand mixed with it. The box containing the putty should be kept covered to keep out dust and dirt, and the putty should not be used until at least a week old.

The skim coat is put on with a trowel, floated down, and then gone over with a brush and small trowel until the surface becomes hard and polished. In the author's opinion this makes a much better finish than the ordinary *white coat*, although it is claimed that the latter is better for walls that are to be painted.

White Coat.—(This term is generally used to designate the finishing coat when plaster of Paris is mixed with the lime putty.) In most portions of the United States it appears to be the custom to finish the walls with a thin coat of lime putty, plaster of Paris and marble dust. This makes a whiter wall than the skim coat, and if marble dust is used and the work is well troweled it will take a good polish. Without the marble dust it will not be as hard nor take a polish. For this work the lime is slaked and permitted to form a putty, as with the skim coat. The plaster and marble dust should not be mixed with the putty until a few moments before using, and then only as much should be prepared as can be used up at once, for if left to stand any length of time it will "set" and become useless. It should be finished by brushing down with a wet brush and immediately going over it with a trowel. The more it is troweled the harder it will become. In estimating the quantity of materials required for the white coat, 90 pounds of lime, 50 pounds of plaster and 50 pounds of marble dust should be allowed to 100 square yards.

Sand Finish.—When a rough finish is desired for fresco work, as in churches, halls, etc., the third coat is mixed with lime putty and sand as for skim coat, except that coarser sand and a greater quantity of it is used. Sometimes a small quantity of plaster of Paris is also mixed with it. Sand finish should be applied before the brown coat is quite dry, and should be floated with either clear, soft pine or cork-faced floats. The roughness of the surface desired may be conveniently designated by comparing it with the different grades of sand paper.

Sometimes the brown coat is floated to give an imitation of sand finish, but it is impossible to get an even and uniform surface without using a separate coat. Sand finish is often ruled off and jointed to imitate stone ashlar. It may also be colored as described on page 356.

HARD WALL PLASTERS.

344. By using only the best materials and mixing them in the manner described it is possible to obtain a very good quality of wall plaster, but there are so many chances of getting an inferior job when ordinary *lime* plaster is used, that a material which can be used with greater certainty is very much to be desired. Such a material appears to be found in the *improved* wall plasters recently placed on the market.

There are now several improved plasters manufactured by different

companies which, although differing in their composition, apparently give about the same kind of wall.

The general name given to these improved or patented wall plasters is that of "hard wall plaster" or mortar.

There are two distinct classes of hard plasters, which may be designated as natural cement plasters and chemical or patented plasters.

Natural Cement Plasters.—In this class are the Acme, Agatite, Aluminite, Climax and Royal, the first and last names being perhaps the best known.

The earth from which these plasters are produced is found in various portions of Kansas and Texas. It is of a light ash-gray color and of about the consistency of hard plastic clay, which it much resembles in appearance, although its chemical nature is more like that of gypsum.

When calcined it assumes a pulverized form. When mixed with water it sets like hydraulic lime or cement, but much more slowly, so that ample time is afforded for applying the mortar.

A sample of agatite, after several weeks setting, broke under a tensile strength of 370 pounds per square inch. It is superior in strength to most of the hydraulic limes and natural cements.*

The various deposits from which the plasters above mentioned are produced appear to be of about the same grade of earth, the plasters differing, if at all, only in their strength and working qualities, which is due principally to slight differences in the process of manufacture.

The Acme cement plaster is produced by calcining the natural earth at a high degree of heat (about 600° Fahr.), which rids the material of not only the free moisture, but also the combined moisture.

The resulting plaster is slow setting, works smooth under the trowel, and does not come to its normal strength until thirty or sixty days after it is spread.

These cement plasters are remarkable for their great adhesive quality. They will stick firmly to stone, brick or wood without the aid of hair or fibre. Acme cement has been used to some extent in New York for setting fireproof tiling, and has been found superior for this purpose to the ordinary natural cements.

Acme cement plaster was the first of this class to be put on the market. It has been extensively used throughout the country, and makes a very superior wall plaster. Large quantities of it were used in plastering the World's Fair buildings, Chicago. Agatite and

* Professor Edwin Walters, in Kansas City *Journal*, January 20, 1893.

Royal, although more recently introduced, have also been quite extensively used, particularly on large and important buildings in the West. Climax is produced especially for the Southern trade.

345. Chemical or Patented Plasters.—In this class are: King's Windsor Cement dry mortar, Adamant, Rock Wall, Granite, and some others not so well known.

The precise composition of these plasters is kept secret, but it is generally understood that they are made from gypsum (plaster of Paris calcined at about 225° of heat), to which some material or chemical is added to *retard* the natural quick setting of the plaster of Paris and make it slow enough setting that it can be mixed with sand and spread upon the wall. As well as the author has been able to discover the facts, the difference in these patented plasters is due principally to the chemical or other material used for the retarder.

The first of these plasters, and the first of all hard plasters placed on the market, was Adamant. This material was first introduced as a substitute for lime plaster at Syracuse, N. Y., in 1886. It is a chemical preparation, and the manufacture of the chemicals is covered by patents. The chemicals are manufactured exclusively at Syracuse, N. Y., by the original company and sold to licensed companies, who prepare and sell the plaster. There are twenty or more of these branch companies scattered throughout the country. The Adamant companies claim that the quality of their plaster is due principally to the chemicals used in its preparation. Adamant has been more extensively used up to this date (1896) than any other of the hard wall plasters.

The Windsor Cement dry mortar is made by mixing certain chemicals with Nova Scotia gypsum of a superior quality to form the cement, and the mortar is made by mixing with the cement washed and kiln-dried pit sand and asbestos fibre, all the materials being accurately weighed and uniformly mixed by special machinery. The mortar is made in the vicinity of New York City. It has been extensively used in many of the best buildings recently built in that city, and to a considerable extent elsewhere.

A preparation, presumably of this class, called Granite Hard Wall Plaster, is made in Minneapolis, and similar preparations are made by local companies in several localities.

As far as the author has been able to ascertain all of these materials give good results when properly handled, although those which have been longest on the market are apt to be the most reliable.

346. How Sold.—All of the plasters above described are packed in sacks, or bags, holding either 100 pounds or a half barrel each.

Acme, Agatite and Royal are sold in the form of cement only, and the sand is mixed with the cement as it is used by the plasterer.

Two kinds of cement are sold, one mixed with fibre and known as fibred cement, and the other without fibre. The fibred cement should be used for the first coat on lathed work, whether of wood or metal. On brickwork, or fireproof tiling, fibre is not required, and the unfibred cement should be used.

The unfibred cement is also used for second or brown coat and wherever the plaster is to be troweled down to a smooth, hard surface. Where the plaster is to be finished with a white surface it is necessary to use lime and plaster of Paris (as on lime plaster) over these cements, as they are of a gray color.

Windsor Cement dry mortar and Adamant are sold mixed with fibre and sand, all ready for applying by simply mixing with clean water. Two grades of the Windsor mortar are made, one for lath work and the other for applying on iron, brick, terra cotta, etc., the only difference between the two being that the latter contains more sand than the former. Adamant is made in eight different grades for base coats on lath, brickwork or tile, for browning coat, and for finishing. Four different kinds of finishing material are made, to give any style of finish desired.

347. Application.—The method of applying these plasters does not differ materially from that already described for lime mortar, except that the second (corresponding to the brown) coat is put on directly after the first coat, and is finished with the darby instead of with the float. Being of the nature of cement, or plaster of Paris, these mortars *set* instead of drying, and but little water should be used in working them. Only as much material should be mixed as can be applied in one and a half hours, and material that *has commenced to set* should never be remixed.

Only clean water should be used, and the tools and mortar box should be kept perfectly clean and the box cleaned out after each mixing.

When using the hard plasters on wood laths, the laths should be *thoroughly dampened*, or expanded, before the plaster is spread, so that they will not swell after the plaster has commenced to set. Brick, stone and tile work should also be *well sprinkled* before applying these mortars.

Most of the manufacturers of hard plasters recommend that when their plaster is to be used the laths be spaced only from $\frac{1}{3}$ to $\frac{1}{4}$ inch apart, and that $\frac{3}{4}$-inch grounds be used, claiming that a less quantity of their material is required than of ordinary lime mortar.

A gentleman who has had much experience with cement plasters, however, says that "More failures are made in using hard plaster by using too thin coats, too weak keys and too weak material (when sold unmixed with sand) than from any other cause.

"To do a good job of hard plastering it is necessary to use a sufficient amount of cement to give it tensile strength, a good wide key, and a good thick coat of plaster. Where it is spread very thin it is sure to crack and give an unsatisfactory wall."

For lath work a better wall will be obtained, although at a little more expense, by putting on $\frac{7}{8}$-inch grounds and having a $\frac{3}{8}$-inch key.

All of these plasters, except Adamant, can be finished with a third coat, as described in Section 343, which should in no case be applied until the base is thoroughly dry.

Sand finish is generally made by mixing sand with the same plaster as is used for the brown coat.

Full directions for applying the various grades of these plasters are furnished by the manufacturers, and architects should see that these instructions are carefully and faithfully followed, as when *improperly applied* these plasters are inferior to the ordinary lime mortar.

348. Advantages.—The principal advantages gained by the use of these plasters are: uniformity in strength and quality, greater hardness and tenacity, freedom from pitting, less weight and moisture in the building, saving in time required for making and drying the plaster, minimum danger from frost and greater resistance to fire and water.

Frost does not harm these mortars after they have commenced to set or the chemical action has taken place. When used in freezing weather they must not be allowed to freeze during the first thirty-six hours after applying; after that time frost will do no harm.

Those plasters which are already mixed with sand and fibre also have the additional advantage of thorough and uniform mixing of the materials and *absolute correctness of proportion.* This latter advantage is perhaps most appreciated by the architect, as it prevents all chance of using a poor quality of sand, or too much of it, and saves him a great deal of labor in the superintendence.

The benefit to the owner in using these plasters consists in securing much more substantial walls than is possible with the ordinary hand-made mortar, less risk from fire and less expense for repairs.

The slight additional expense of using them is hardly to be considered in comparison with the benefits obtained, and it is probable that these plasters will in a short time become generally adopted, they being already extensively used in the largest and most costly buildings.

For business buildings the saving in the time required in drying the plastering will more than pay for the additional expense.

On account of their greater density these mortars will not harbor vermin nor absorb noxious gases or disease germs, and are therefore especially desirable for hospitals, schools, etc. Heat, air and moisture will not pass through them as through lime plaster.

A wall of hard plaster, wood or metal lath is also much more resonant than one of lime mortar, and for this reason, and also on account of their greater strength, these mortars should be especially valuable for plastering churches, opera houses and public halls.

STUCCO WORK.

349. This term, as commonly used in this country, refers to ornamental interior plaster work, such as cornices, mouldings, centrepieces, etc. For such work a mixture of lime paste and plaster of Paris is used, except for cast work, which is made entirely of plaster of Paris.

Plaster of Paris is produced by the gentle calcination of gypsum to a point short of the expulsion of the whole of the moisture. Paste made from it sets in a few minutes, and attains its full strength in an hour or two. At the time of setting it expands in volume, which makes it especially valuable for taking casts and for making cast ornaments for walls and ceilings, and also for patching and repairing ordinary plaster work.

When added to lime mortar, plaster of Paris causes the mortar to set or harden very quickly, and for this reason it is often mixed with mortar to be used for patching or repairing, or where it is necessary to have the plaster harden very quickly. When this is done it is called "gauged work."

Plaster of Paris is very liable to crack when used clear and in considerable thickness. Cast ornaments made of it are therefore usually made hollow, or with a thin shell. For work that is to be run, or worked by hand, it cannot be used clear, as it sets too quickly. It is for this reason that lime putty is mixed with it.

For mouldings, cornices, etc., about 2 parts of plaster of Paris to 1 of lime paste is used.

Plain mouldings, whether in a cornice, centrepiece, or on the wall or ceiling, are usually "run" in place by hand. The process consists in placing on the surface of the wall or ceiling a sufficient body of plaster and forming the mould by running along it a sheet iron template, cut to the reverse profile of the mould. The template is stiffened by wooden cleats, and provided with struts to keep the plane of the template always perpendicular to the plane of the surface on which the mould is run. The stucco work is always run before the

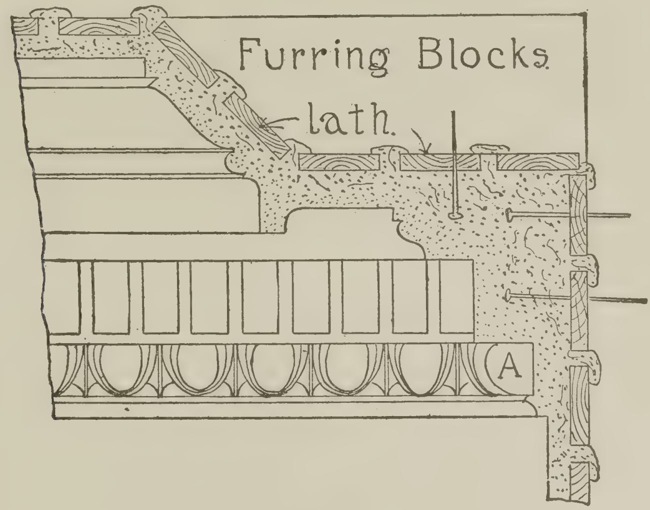

Fig. 232.

finishing coat of plaster is applied, as it is necessary to fasten light pine straight-edges on the wall to form guides for the templates. In running the moulding two men are generally required, one to put on the plaster as it is needed and the other to work the template, which generally has to be worked back and forth several times before the moulding is finished.

The whole moulding or cornice between any two breaks or projections should be completed at once, so that the entire length may be uniform in shape and shade.

The mitres at the angles, both internal and external, have to be finished by hand, using a small trowel and straight-edge.

If the cornice or moulding contains much ornamental work, it is cheaper to cast it in sections of about 2 feet in length, and attach to the wall by means of liquid plaster of Paris. It requires great care in cast work to have the sections join nicely, so that the members will present a perfectly straight line.

If there are only one or two enriched members, the rest of the moulding or cornice may be run in the usual way, leaving sinkings to receive the enriched members, which are then cast and stuck in place, as at *A*, Fig. 232.

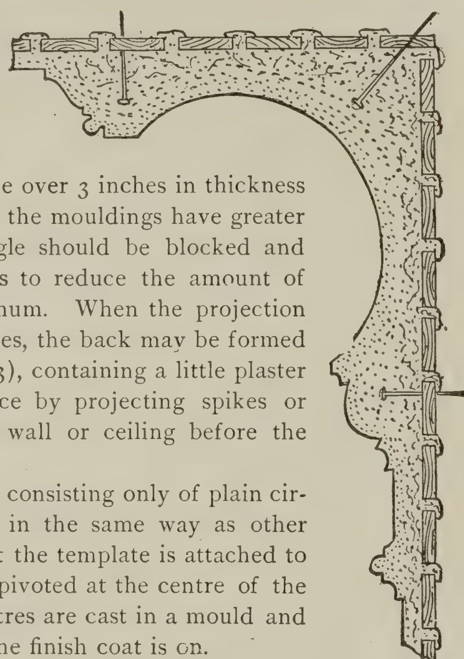

Fig. 233.

In designing cornices or belt mouldings, care should be taken not to have over 3 inches in thickness of plaster at any point. If the mouldings have greater than this the wall or angle should be blocked and lathed, as in Fig. 232, so as to reduce the amount of plaster required to a minimum. When the projection is only about $3\frac{1}{2}$ or 4 inches, the back may be formed of brown mortar (Fig. 233), containing a little plaster of Paris, and held in place by projecting spikes or large nails, driven into the wall or ceiling before the mortar is put on.

Centre ornaments, when consisting only of plain circular mouldings, are run in the same way as other moulded work, except that the template is attached to a piece of wood which is pivoted at the centre of the ornament. Enriched centres are cast in a mould and stuck to the ceiling after the finish coat is on.

All kinds of ornaments, such as paneled ceilings, *bas-reliefs*, imitations of foliage, etc., may readily be executed in plaster of Paris, and when the ornament is placed in such positions that it cannot readily be injured by objects in the room, it answers as well as harder and more expensive materials.

Since hard wood finish has become so prevalent, however, it has largely supplanted the plaster cornices that were so common fifty years ago.

Stucco work is generally included in the plasterer's specifications. As it is much more expensive than ordinary plastering, the quantity and character of it should be clearly indicated on the drawings and in the specifications, and by full size details.

For enriched work the architect should require that the models be approved by him before the casts are made.

350. Keene's Cement.—When it is desired to finish plaster walls, ceilings, columns, etc., with a very hard and highly polished surface, Keene's cement is generally used for the finishing coat. This cement is a plaster produced (in England) by recalcining plaster of Paris after soaking it in a saturated solution of alum. This material is very hard and capable of taking a high polish, and walls finished with it may be sponged with soft water without injury.

It is especially valuable for finishing plastered columns, the lower portions of walls, and wherever the plaster is liable to injury from contact with furniture, etc. It is also used in the manufacture of artificial marble.

The manufacturers of King's *Superfine Windsor Cement* claim that for finishing walls it is equal to the imported Keene's cement; it is considerably less expensive.

Neither of these materials should be used in situations much exposed to the weather, on account of their solubility.

351. Scagliola is a coating applied to walls, columns, etc., to imitate marble. The base or ground work is generally of rich lime mortar containing a large proportion of hair. After this has set and is quite dry it is covered with a floated coat, consisting of plaster of Paris or Keene's cement, mixed with various coloring matters in a solution of glue or isinglass, to give greater solidity and to prevent the plaster of Paris from setting too quickly. When the surface is thoroughly hard it is rubbed with pumice stone and then polished until it looks like polished marble. Columns can be made in this way that can hardly be detected by the eye from marble.

Imitation marble, when in flat slabs, is commonly made on sheets of plate glass. Threads of floss silk, which have been dipped into the veining colors, previously mixed to a semi-fluid state with plaster of Paris, are placed upon a sheet of plate glass so as to resemble the veins in the marble to be imitated. Upon this the body color of the marble is placed by hand. The silk is then withdrawn and dry plaster of Paris is sprinkled over to take up the excess of moisture and to give the plaster the proper consistency. A backing of cement or plaster of Paris is then applied of any desired thickness. Canvas is sometimes placed in the backing to give greater strength. After removing from the glass the slab is polished and set in place in the same manner as the genuine material. This work naturally requires much skill in the workman, besides practice and experience

A great deal of scagliola has been used in Europe, and in recent years several companies have been formed in America for making artificial marble, which is essentially the same thing. For interior work scagliola should be as durable as marble, and there are columns of it in Europe several hundred years old. It should not be used on the exterior of buildings, as it will not bear exposure to the weather.

352. **Fibrous Plaster** consists of a thin coating of plaster of Paris on a coarse canvas backing stretched on a light framework and formed into slabs. For casts about $\frac{1}{4}$ inch of plaster is put in the mould, and the canvas is then put on the back and slightly pressed into the plaster. Fibrous plaster is very light and strong, and can be easily handled without breaking. It is extensively used in England for ornamental work, and in Brazil it is said to be used extensively for external work.

Carton Pierre is a material used for making raised ornaments for wall and ceiling decoration. It is composed of whiting mixed with glue and the pulp of paper, rags and sometimes hemp, which is forced into plaster or gelatine moulds, backed with paper, and then removed to a drying room to harden. It is much stronger and lighter than common plaster of Paris ornaments, and is not so liable to chip or break if struck with anything.

Ornaments of carton pierre (under different names) are now extensively used in this country for decorating rooms, mantels, etc., and also to some extent on the exterior of buildings. If kept painted there appears to be no reason why it should not last for many years, except in very exposed positions.

EXTERNAL PLASTERING.

353. This is generally either rough-cast or stucco. The first is a description of coarse plastering, generally applied on laths ; the second is a description of plastering on brickwork, executed so as to resemble stone ashlar.

Rough-cast has been extensively used in Canada, and to some extent in the Northern States. It is said to be much warmer than siding or shingles, less expensive, and quite as durable. It is also more fire-resisting.

" There are frame cottages near the city of Toronto and along the northern shores of Lake Ontario that were plastered and rough-casted exteriorly over forty years ago, and the mortar to-day is as good and sound as when first put on, and it looks as though it was good for

many years yet if the timbers of the building it preserves remain good.

"It is quite a common occurrence in Manitoba and the northwest Territories in the winter to find the mercury frozen, yet this intensity of frost does not seem to affect the rough-casting in the least, though it will chip bricks, contract and expand timber and render stone as brittle as glass in many cases."*

Frame buildings to be rough-casted should be covered with sheathing and one thickness of tarred paper. The partitions should be put in and even lathed before the outside is plastered, as it is important to have the building stiff and well braced.

The best mode of rough-casting, as practiced in the lake district of Ontario, is said to be as follows:

Lath over the sheathing (or tarred paper if used) diagonally with No. 1 pine laths, keeping $1\frac{1}{2}$ inches space between the lath; nail each lath with five nails and break joints every 18 inches; over this lath diagonally in the opposite direction, keeping the same space between the laths and breaking joint as before. Careful and solid nailing is required for this layer of lathing, as the permanency of the work depends to some extent on this portion of it being honestly done. The first coat should consist of rich lime mortar, with a large proportion of cow's hair, and should be mixed at least four days before using. The operator must see to it that the mortar be well pressed into the key or interstices of the lathing to make it hold good. The face of the work must be well scratched to form a key for the second coat, which must not be put on before the first or scratch coat is *dry*. The mortar for the second coat is made the same as for the first coat, and is applied in a similar manner, with the exception that the scratch coat must be well damped before the second coat is put on, in order to keep the second coat moist and soft until the dash or rough-cast is thrown on.

The dash, as it is called, is composed of fine gravel, clean washed from all earthy particles and mixed with pure lime and water till the whole is of a semi-fluid consistency. This is mixed in a shallow tub or pail and is thrown upon the plastered wall with a wooden float about 5 or 6 inches square. While the plasterer throws on the rough-cast with the float in his right hand, he holds in his left a common whitewash brush, which he dips into the dash and then brushes over the mortar and rough-cast, which gives them, when finished, a regular uniform color and appearance.

For 100 yards of rough casting, done as above described, the following quantities will be required: 1,800 laths, 12 bushels of lime, $1\frac{1}{2}$ barrels best cow hair, $1\frac{3}{4}$ yards of sand, $\frac{3}{4}$ yard of prepared gravel and 16 pounds of cut lath nails, $1\frac{1}{4}$ inches long. A quarter barrel of lime putty should be mixed with every barrel of prepared gravel for the dash. The dash may be colored as desired by using the proper pigments.

To color 100 yards in any of the tints named herewith use the following quantities of ingredients: For a blue-black, 5 pounds of lampblack; for buff, 5 pounds of green copperas, to which add 1 pound of fresh cow manure, strained, and mixed with the dash. A fine terra cotta is made by using 15 pounds of metallic oxide, mixed

* "Rough Casting in Canada," by Fred. T. Hodgson, *Architecture and Building*, March 24, 1894.

with 5 pounds of green copperas and 4 pounds of lampblack. Many tints of these colors may be obtained by varying the quantities given. The colors obtained by these methods are permanent; they do not fade or change with time or atmospheric variations. Earthy colors, like Venetian red and umber, soon fade and have a sickly appearance.

Expanded metal, perforated, or stiffened wire lathing are undoubtedly better than wood laths for external plastering, as they hold the plaster better and also afford greater protection from fire.

The following description of external plastering, as used by an architect of considerable experience with this sort of work, was published in the *Brickbuilder* for August, 1895, and probably represents the best current practice in this country:

> I have always used three-coat work, the first well-haired mortar and one-third Portland cement, added when ready for use; this coat well scratched. The second coat the same, with the omission of the hair, and the third coat the same proportion, but with coarse sand or gravel, either floated or put on slap-dash, according to the kind of finish I wished to obtain.
>
> I have occasionally used a very small quantity of ochre in this last coat, but it must be mixed very thoroughly and carefully in order to produce an even color.
>
> This plaster work I have used on wood lath over stud without rough boarding behind it. Also on rough boarding with furrings and wood lath, which is better; and over rough boarding with furrings and wire lath, which is the best of all.
>
> A small church plastered in this way on wood lath fourteen years ago is in perfect condition to-day, and various houses built during the last ten years have proved perfectly satisfactory. I have not as yet, however, found any method of building true half-timbered work and making it thoroughly tight without making a wall that was practically as expensive as a brick wall.

354. **External Stucco.**—External plastering of buildings was at one time greatly in vogue in European countries, and there are many examples of "stucco"-covered buildings in the older portions of this country. Formerly lime and sand were used for the purpose, but this material is not very durable. If it is desired to plaster a brick building to imitate stone ashlar, Portland cement is the only material that should be used. It should be mixed with clean sharp sand, not too fine, in the proportion of 3 parts sand to 1 of cement. The wall to be covered should itself be dry, but the surface should be well wet down with a hose to prevent it from absorbing at once all the water in the cement; it should also be sufficiently rough to form a good key for the cement. Screeds may be formed on the surface, and the cement should be filled out the full thickness in one coat and of uniform substance throughout. When cement is put on in two or three coats, whether for exterior or interior work, the coats already applied

should on *no account be allowed to dry* before the succeeding layers are added, otherwise they are quite sure to separate.

The manufacturers of Acme cement plaster claim that where brick buildings are to be plastered with cement on the outside, that their plaster is superior to Portland cement for the first coat, as it adheres more firmly to the brick, and will hold the Portland cement and the base upon which it is spread together.

The cement may be marked with lines to represent stone ashlar before it becomes hard. If it is desired to color the cement, mineral pigments must be used, such as Venetian red or the ochres. The natural color of the cement may be lightened by the addition of a very little lime.

STAFF.*

355. Staff, a material used for the exterior covering of all the buildings of the World's Columbian Exposition at Chicago, may be considered as almost a new material in this country, although it has been in extensive use in Europe for many years. A large part of all exterior decoration of buildings, both public and private, in the provincial cities of Germany, whether ornament, columns or statuary, is made of staff, and in instances a period of fifty years of existence will testify to its enduring qualities. Staff was first used extensively in the construction of buildings at the Paris Exposition of 1878, and it was also adopted in work on the much grander buildings of the exposition of 1889. The methods of application at these expositions were, however, widely different from and much more expensive than those employed at the Columbian Exposition.

The staff for the World's Fair buildings was made on the grounds at Jackson Park in the following manner:

The ingredients were simply plaster of Paris, or Michigan plaster, water and hemp fibre. Hemp was used to bind together and add strength to the cast, and the New Zealand fibre was preferred, as both the American and Russian fibres were found too stiff. The first step in making staff ornaments is the creation of a clay model. The model is heavily coated with shellac, and a layer of clay separated from the model by paper is put on its face and sides. This layer of clay is oiled or greased and a heavy coating of plaster and hemp is put over it. The thickness of this coating is dependent upon the size of the model; sometimes it is 5 or 6 inches thick and contains heavy battens of wood to strengthen it. In less than twenty-four hours this coating is hard and is taken off the clay covering the model. The coating thus removed is called the box. Next the clay is removed from the model and the model

* The following description of this material is taken from an article by E. Phillipson, published in the *Engineering Record* of June 4, 1892. Mr. Phillipson had charge of this portion of the work on the World's Fair buildings.

is thoroughly oiled. The box is oiled and put over the model, leaving the space between model and box formerly taken up by the clay coating a free space. Holes have previously been made in the box, and upon a large centre hole (sometimes two or three in large pieces) a plaster funnel is placed. Molten gelatine is poured through these funnels, which fills every space, air being allowed to escape through small holes in the box. In from twelve to twenty-four hours the box is again removed, placed hollow side up, and the now hardened gelatine is removed from the clay model and placed in the box, which it fits perfectly. The clay model has now served its purpose, for the gelatine, which has become a matrix of the cast desired, is used in the further stages of the work. In case of large moulds the gelatine matrix is sometimes cut into as many as eight pieces. All these, of course, join perfectly in the box and are cast from as if from a single matrix. The gelatine mould is washed a number of times with a strong solution of water and alum, and after oiling is ready for the operation of casting.

The plaster for the staff is thoroughly stirred in water, and the hemp, cut into lengths of 6 to 8 inches, is bunched loosely, saturated with the plaster and put in the moulds in a layer of about 1 inch in thickness. Succeeding handfuls of hemp are thoroughly interwoven with the preceding, the hemp being expected to fill in all the corners of the cast. When the mould is filled the back is smoothed over by hand, and later the cast is removed from the mould. The time consumed from starting a cast to removing it from the mould, is for a cast 5'x2'6" in size, about twenty-five minutes. After the removal of the cast care must be exercised in either standing it up or laying it down that it shall not collapse or lose its form by warping. During the summer months a cast of the dimensions given will dry thoroughly in about thirty-six hours and is then ready for application. In the winter months there is danger of casts freezing before they are dry, and in that event they are apt to go to pieces when warm weather comes. A good workman can make as many as seventy-five casts in one mould, and then the gelatine is remelted and a new mould made of it, the box being good for use for an indefinite length of time. In making pilasters or mouldings, etc., not ornamented or under-cut, plaster and wood moulds are often used, the latter material being especially preferred, owing to its durability.

"Applied to a frame building, staff is simply nailed on to the rough construction, and a cheap brick wall covered with it can, at a comparatively small expense, be made to assume a classic appearance. In building a brick house with the employment of staff in view, it is advisable to insert wooden furring strips in the brick, as these simplify the labor of putting it on. For cornice work it is claimed that a strength and boldness of design are possible with staff which cannot be realized with other materials.

"At the Paris Exposition the buildings were constructed almost entirely of iron, and nearly all the staff was cast in panels, which were set in iron frames. While this method was considered excellent, both in finished effect and in durability, it was far too expensive and tedious to be employed in covering the much more extensive structures to be built for the World's Columbian Exposition Accord-

ingly, after many weeks of study, the construction department decided to construct the buildings of wood and to nail the staff directly to the furring.

"The name 'staff' properly applies to material that is cast in moulds, and not to ordinary plaster or cements that are put on with a plasterer's trowel. Work with such materials is subject to well-understood limitations by the temperature and weather, but atmospheric influences have practically no effect upon staff. This has been demonstrated by the acres of staff that has been standing all winter outside the various casting shops in Jackson Park. No attempt has been made to keep off the rain, snow or frost. Several pieces of it have been submerged for over a month at a time, allowed to freeze and thaw, and freeze again with the water, and when taken out they were found to be perfectly intact."

While this material admirably answered its purpose on the Fair buildings, it became considerably deteriorated, and evidently would not answer in such a climate for permanent buildings unless kept well painted. In fact, it appears to be generally conceded that Portland cement is about the only material that will endure permanently under the trying conditions of our northern climate. In warmer and dryer climates compositions of plaster are largely used on the exterior of buildings, and in many instances they have lasted for centuries.

The cost of "*staff*," as used on the World's Fair buildings, varied from $2 to $2.25 per square yard. Ordinary cement mortar applied directly to the walls cost about thirty cents per yard.

356. Whitewashing.—Although not properly belonging to the plasterer's trade, this work is often included in the plasterer's specifications.

Common whitewash is made by simply slaking fresh lime in water. It is better to use boiling water for slaking. The addition of 2 pounds of sulphate of zinc and 1 of common salt for every half bushel of lime will cause the wash to harden and prevent its cracking. One pint of linseed oil, added to a gallon of whitewash immediately after slaking, will add to its durability, particularly for outside work. Yellow ochre, lampblack, Indian red or raw umber may be used for coloring matter if desired.

Whitewash not only prevents the decay of wood, but conduces greatly to the healthiness of all buildings, whether of wood or stone. It does not adhere well, however, to very smooth or non-porous surfaces. Two coats of whitewash are required on new work to make a good job.

LATHING AND PLASTERING IN FIREPROOF CONSTRUCTION.

357. Wherever lathing is required in buildings that are intended to be thoroughly fireproof, only stiffened wire or expanded metal lath should be used. If one of the hard plasters are to be used, close-warp ($2\frac{1}{2}$x5 mesh) should be specified, and the lathing should be either painted or galvanized. (See Section 333.)

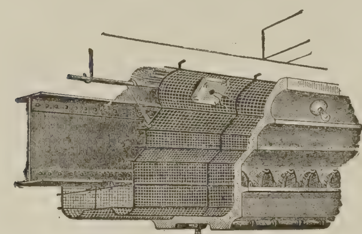

Fig. 234.

In buildings having hollow tile floor construction but very little, if any, lathing is used, as all the walls, ceilings and partitions are of tile, on which the plastering is directly applied. For such buildings either machine-made lime mortar (such as is described in Section 340) or one of the hard plasters should be used.

Cornices, false beams, etc., in this class of buildings are more

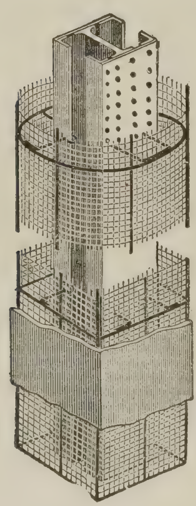

Fig. 235.

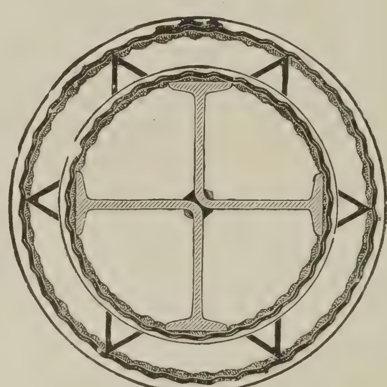

Fig. 235a.

commonly formed by furring with light iron and covering with metal lath, to which the plastering is applied.

The method of forming a beam and cornice in this way is shown by Fig. 234. The general profile is formed by bending light iron by

hand on a shaping plate to the desired outline. These are secured in position and longitudinal rods fastened to their angles, after which the wire lathing is applied.

Fig. 235 shows the manner of furring steel and iron columns when protected by wire lath and plaster, and Fig. 235*a* a popular method when expanded metal is used.

Both wire lath and expanded metal have been very extensively used for furring elaborate ceilings, beams, arches, vaults, etc., in public buildings, and wherever such furring has been removed or examined after a term of years, it has always, so far as known, been found to be in good condition and free from rust.

The larger portion of the plaster beams and ceilings, domes, etc., of the new Congressional Library are formed with expanded metal on iron furrings, also the very elaborate ceiling of the dining room in the Chicago Athletic Club and the domes and paneled ceilings of the New York Clearing House.

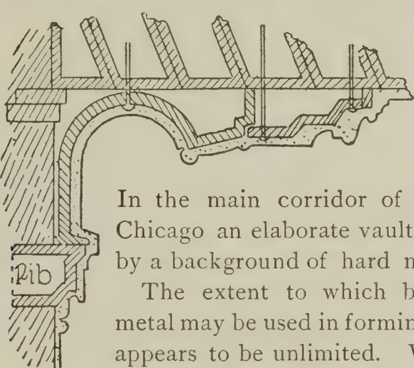

Fig 236.

In the main corridor of the Worthington Building in Chicago an elaborate vaulted mosaic ceiling is supported by a background of hard mortar on expanded metal.

The extent to which both wire lath and expanded metal may be used in forming a base for mortar and cement appears to be unlimited. When hollow tiles are used for fireproofing, the grounds for the cornices are sometimes formed of terra cotta, as shown in Fig. 236. Such grounds are more firm to carry the heavy stucco, and the plastering is not as liable to be broken by streams of water in case of fire. They are, therefore, generally preferred to metal grounds, and are used almost entirely in the U. S. Government buildings when the ceilings are of tile.

The various pieces forming the ground should be bolted to the floor construction with ¼-inch T-head bolts spaced not over 12 inches apart longitudinally, and at least two bolts to each piece.

These terra cotta grounds are usually made by manufacturers of flue linings and pipes, as their machinery is better adapted for the purpose than that used for making fireprooof tile.

358. Thin Partitions of Metal Lath and Studding.—As stated in Section 320, partitions only 2 inches thick are now quite extensively used in office buildings and hotels to economize floor

space. Most of these partitions are constructed of upright studding of $\frac{3}{4}$-inch channel bars spaced from 12 to 16 inches on centers and fastened securely to the floor and ceiling. On one side of this studding, metal lathing, preferably of stiffened wire cloth, or expanded metal, is stretched and securely laced to the studs. The partition is then plastered on both sides with hard plastering and finished in the usual manner. If properly executed the partition will be stiff enough to answer all the purposes for which it is required, and is, of course, absolutely fireproof. Only the best of hard wall plasters should be used for such partitions, however, as the stiffness of the partition depends very much upon the solidity of the plastering; hence the firmer and harder the plastering the more substantial will be the walls. By using 2-inch channels and lathing both sides a very stiff partition is obtained, but, of course, at greater expense.

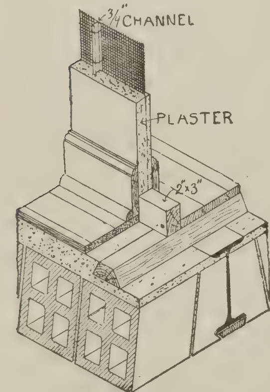

Fig. 237.

The New Jersey Wire Cloth Co. makes a special lathing for thin partitions, which has a $\frac{1}{4}$-inch solid rod woven in at intervals of $7\frac{1}{2}$ inches. The lath is stretched over the studs so that the rods cross them at right angles. The lath, after being tightly stretched, is laced to the studs at every point where the rods cross them.

Expanded metal has been very extensively used in the construction of solid partitions. It is applied the same way as wire lath (by soft steel wire), except that being in flat sheets it does not require stretching. Perforated sheet metal lathing, when used, is generally secured to the studding by trunk nails driven through the lath along side of the stud and clinched around behind it, each nail being driven on the opposite side of the stud from the one above and below.

Provisions for Base and Picture Mould.—If wire lath of the standard mesh is used some provision must be made for securing the wooden base and picture mould.

Fig. 237 shows the method ordinarily adopted for securing the base. For securing the picture mould, strips of wood may be laced to the lath at the required height before plastering.

When imbedded in the plaster these strips are sufficiently firm to hold the picture mould. The mould should be put up with screws, however, and not with nails.

When close-warp lathing, plastered with mortar, is used, No. 14 or 16 screws will engage in the meshes of the wirework, and all woodwork can be fastened directly to the partition with wood screws.

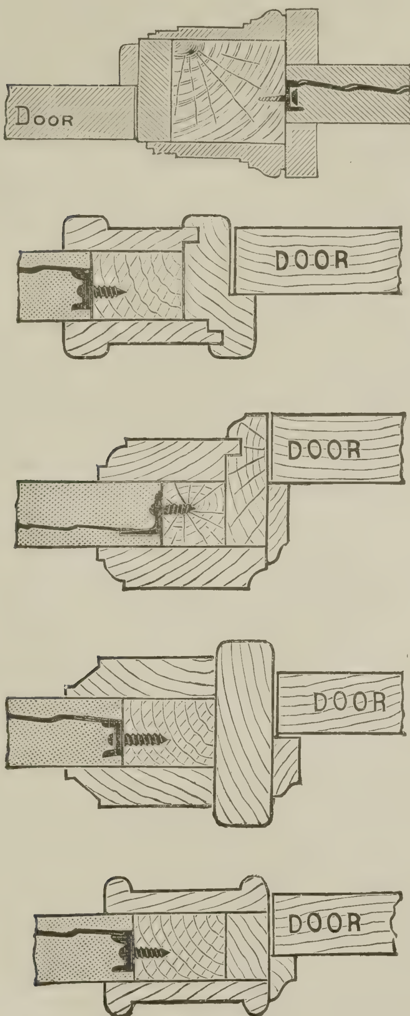

Fig. 237*a*.

Door and Window Framing.—The usual method of framing for doors and windows has been to set up rough wood frames, to which the adjoining channel is securely fastened by screws or anchor nails, and in most cases this method is quite satisfactory.

Fig. 237*a* shows various styles of door frames, which differ principally in the character of the finish. Those sections which have the widest door jambs will be found the stiffest. Various modifications of these details may be made to suit the judgment or taste of the architect.

Fig. 237*b* shows one method of constructing the window frames in corridor partitions. The style of moulding may be varied to suit the taste of the designer.

In warehouses where there is to be heavy trucking, or where iron or fireproof doors are to be used, the door frame may be built of $1\frac{1}{2}$x$1\frac{1}{2}$-inch angle iron, to which the first stud of the partition should be riveted.

In extremely large doorways and on freight elevators it is often a

practice to make the frames of heavy 2-inch channel iron, to which are hung the large fireproof doors.

Partitions of thin porous tiling were described in Chapter IX., Section 320.

For forms of specifications for solid partitions see pages 389 and 390.

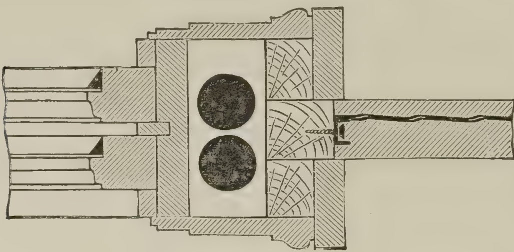

Fig. 237*b*.

PLASTERING SUPERINTENDENCE.

359. This consists chiefly in seeing that the work is performed in accordance with the specifications, and if the specifications are properly written much of the vexation of superintendence will be saved. The points which the superintendent should particularly inspect are the following:

Quality of Materials.—See that the laths are of the kind specified, and, if of wood, that they are free from bark and dead knots. If any such laths have been put on have them removed and clean, sound laths substituted. See that the lime is of the kind specified; if it is not in casks it will be well to require the plasterer to produce the bills for the lime; also that the lime is fresh and in good condition. Permit no lime that has commenced to slake to be used. Inspect the sand to see that it is free from earthy matter, and that it is properly screened. Make a note of the time the plasterer commences to make the mortar, and do not permit him to use it until it is at least seven days old, or as required by the specifications.

As to the proportions of the lime, sand and hair, not much can be told by the superintendent, unless he has the quantities measured in his presence, which will involve his being on the ground most of the time. Something, however, of the quality of the mortar and of the amount of hair may be determined by trying it with a trowel. The superintendent should endeavor to make himself familiar with the appearance of good mortar. See that the hair is mixed with the

mortar at the stage specified, and in no case permit it to be mixed with the hot lime.

Lathing.—Before the workmen commence to put on the laths the architect or superintendent should carefully examine all grounds and furring to see that they are in the right place and are plumb and square. If the chimney-breasts are furred, as is the custom in the Eastern States, they should be tried with a carpenter's square to make sure that their external and internal angles are right angles; also see that all angles of partitions are made solid, so that there can be no lathing through the angles.

If wooden laths are used, see that they are well nailed and that they are not placed too near together; $\frac{3}{8}$ of an inch should be allowed on ceilings and $\frac{1}{4}$ to $\frac{5}{16}$ on walls.

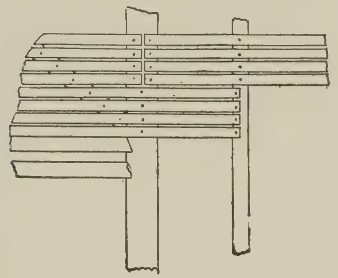

Fig. 238.

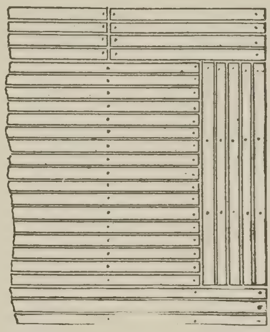

Fig. 239.

See that the end joints are broken at least every 18 inches; if the lather will do so, it is better to break joint in every course.

See that the laths over door and window heads extend at least to the next stud beyond the jamb (as in Fig. 238), so as to prevent cracks which are apt to appear at that point; also see that all the laths run in the same direction. When laths run in different directions (as in Fig. 239) cracks are sure to appear where the change takes place. See that all recesses in brick walls for pipes, etc., are covered with wire or expanded metal lathing, unless they are to be covered with boards.

Also see that all wood lintels and other solid timbers that are not furred are covered with metal lath. The juncture of wood with brickwork should also be covered with metal lathing. If any kind

of metal lathing is used see that it is put up as directed by the manufacturers, and that all wire lathing is tightly stretched ; see that the furrings are properly spaced and that the whole is well secured.

Before the plasterers commence work the superintendent should see that the building is closed in by the carpenter, either by filling the openings with boards, old sash or cloth. Cotton cloth is the best material for the purpose, as it permits of some circulation of air through it.

If the plastering is done in cold or freezing weather provision must be made for heating the building. Ordinary lime plaster is completely ruined by freezing and thawing, and plastering that has once been frozen will never become hard and solid.

When the scratch coat is partly on the superintendent should try to look behind the laths to see if the mortar has been well pushed through between them, as the clinch, or key, at the back of the laths is all that holds the plaster in place.

See that the first coat is dry before the second is put on, if so specified ; also that the surface of the brown coat is brought to a true plane, the angles made straight and square, the walls plumb and the ceilings level. The specifications should require that the first and second coats be carried to the floor, behind the base or wainscoting.

When brick walls are to be plastered the superintendent should remember that a much firmer job of plastering will be obtained if the wall is well wet just before the plastering is applied.

If the first and second coats have been properly put on the finish coat will need little superintendence beyond seeing that proper materials are used and that the work is well troweled, if hard finish.

If any of the improved plasters described in Sections 344–5 are used, the superintendent should see that the instructions furnished by the manufacturers are strictly followed, particularly as to the wetting of the laths and the proportion of sand used ; he should also see that no mortar that has commenced to set is remixed. When machine-made lime mortar, or any of the hard plasters that are sold already mixed with sand and fibre, are specified, the care of superintendence will be greatly lessened. If improved plasters are used in freezing weather the building must be kept above the freezing point until the plaster has set.

360. Measuring Plaster Work.—Lathing is always figured by the square yard and is generally included with the plastering, although in small country towns the carpenter often puts on the laths.

Plastering on plain surfaces, as walls and ceilings, is always meas-

ured by the square yard, whether it be one, two or three-coat work, or lime or hard plaster.

In regard to deducting for openings, custom varies somewhat in different portions of the country, and also with different contractors. Some plasterers allow one-half the area of openings for ordinary doors and windows, while others make no allowance for openings less than 7 square yards.

Returns of chimney breasts, pilasters and all strips less than 12 inches in width should be measured as 12 inches wide. Closets, soffits of stairs, etc., are generally figured at a higher rate than plain walls or ceilings, as it is not as easy to get at them. For circular or elliptical work, domes or groined ceilings, an additional price is also made. If the plastering cannot be done from tressels an additional charge must be made for staging.

Stucco cornices or paneled work are generally measured by the superficial foot, measuring on the profile of the moulding. When less than 12 inches in girth they are usually rated as 1 foot. For each internal angle 1 lineal foot should be added, and for external angles, 2 feet.

For cornices on circular or elliptical work an additional price should be charged.

Enriched mouldings are generally figured by the lineal foot, the price depending upon the design and size of the mould.

Whenever plastering is done by measurement the contract should definitely state whether or not openings are to be deducted, and a special price should be made for the stucco work, based on the full size details.

361. Cost.—The cost of lime plastering on plain surfaces, including wooden laths, varies from twenty to thirty-five cents per yard, according to the times, locality, number of coats and quality of work. For ordinary three-coat work, with white finish, twenty-five cents is probably about the average price for the entire country. The author has known very good work to be done at twenty cents per yard, but there was no profit above the wages of the men.

Hard plasters cost from two to ten cents per yard more than lime plaster, according to the price of lime and freightage on the hard plaster.

Wire or metal lathing will cost from twenty-five to forty cents per yard more than if wood laths were used.

The following figures give the average price for various kinds of plastering in the cities of New York and St. Louis :

DESCRIPTION OF WORK.	AVERAGE COST IN CENTS PER SQUARE YARD.	
Lime Mortar:	New York.	St. Louis.*
[1] Two-coat work on brick or tile	30 to 35	17 to 21
[1] Three-coat work on wood laths	35 to 40	20 to 25
[1] Three-coat work on stiffened wire lath[3]	70	..
[1] Three-coat work on expanded metal[3]	..	55
[2] Windsor Cement or Adamant on brick or tile	40	..
[2] Acme or Royal cement plaster on brick or tile	40	22 to 26
[2] Windsor Cement or Adamant on stiffened wire lath[3]	75	..
[2] Acme or Royal cement plaster on stiffened wire lath[3]	75	60
Cost of stiffened wire lath on wood joist, about	35	..
Cost of expanded metal on wood joist	24	30
Cost of Bostwick lath on wood joist	..	25
Stucco cornices, less than 12 inches girth, per lineal foot.	20	20
When more than 12 inches girth, cost per square foot	24	20
Enrichments cost from 8 cents up per lineal foot for each member.		

1. The last coat to be white finish.
2. Finished with lime putty and plaster.
3. When applied on wood joist or furring : when applied over metal furrings the cost is about 20 cents per yard more.

For scratch and brown coats on wood laths, with $\frac{3}{4}$-inch grounds, the following quantities of materials should be required to 100 square yards : 1,400 to 1,500 laths, 10 pounds of three-penny nails, two and one-half casks or 500 pounds of lime, 45 cubic feet or fifteen casks of sand and four bushels of hair.

For the best quality of white coating allow 90 pounds of lime, 50 pounds of plaster of Paris and 50 pounds of marble dust.

Colored Sand Finish.—In most instances where sand finish is used on interior walls, it is with the purpose of afterward decorating in water color. In such cases the finish itself may be colored or stained at a slightly less expense than with water color, and with the advantage that, the finish being stained throughout its entire mass, dents and scratches will not show, as in the case of paint or kalsomine. For coloring sand finish, pulp stains of the best quality should be used; these are mixed with water to a thick cream and then thoroughly mixed with the finishing mortar, all the mortar for one room being mixed at one time to get it uniform. No plaster of Paris should be used in colored sand finish, as it will streak the wall. Dry colors, also, should not be used, as they are quite sure to prove a failure.

* These prices are about the average asked in the West.

Chapter XII.

CONCRETE BUILDING CONSTRUCTION.

362. Concrete composed of broken stone, fragments of brick, pottery, gravel and sand, held together by being mixed with lime, cement, asphaltum or other binding substances, has been used in construction to resist compressive stress for many ages.

The Romans used it more extensively than any other material, as the great masses of concrete, once the foundations of large temples, palaces and baths, the domes, arches and vaultings still existing, together with the core or interior portions of nearly all the ancient brick-faced walls found in Rome, testify.

In the forest of Fontainbleau there are three miles of continuous arches, some of them fifty feet high, part of an aqueduct constructed of concrete and formed in a single structure without joint or seam. A Gothic church at Vezinet, near Paris, that has a spire 130 feet high, is a monolith of concrete. The lighthouse at Port Said is another, 180 feet in height.

The breakwaters at Port Said, Marseilles, Dover and other important ports, are formed of immense blocks of concrete. The water pipes and aqueduct at Nice, and the Paris sewers, are also notable modern constructions of the same material.

In England and France thousands of dwellings have been built of concrete, in place of brick and stone. Many of these are now standing, after more than half a century, without the least sign of decay. In the United States concrete buildings are comparatively few, the only notable building not of recent date being the large barn built at Chappaqua, N. Y., by Horace Greeley, more than thirty-five years ago, of an ordinary kind of concrete; this building has stood the test of exposure and is as good to-day as when built.

The architects, engineers and capitalists of the United States appear to have been the most timid of those of all civilized nations to avail themselves of the value of concrete as a building material, and it is only since the year 1885 that this material has been used to any

extent in the construction of buildings except for the purpose of footings of foundation walls.

Suitable materials for making concrete are available in almost every locality, and in most places solid walls of concrete are cheaper and more enduring than those of brick or stone.

A concrete building needs no furring, as the walls are proof against dampness, and in a monolithic construction of concrete no possible danger to the structure can arise from fire within or without the building.

While concrete in any form is not likely to take the place of stone, brick or terra cotta for architectural work to any great extent, yet the author believes that in combination with iron and steel it is destined to fill a large place in the construction of buildings, and that for warehouses, large stables, wine cellars, etc., it is the best and cheapest material for producing substantial and incombustible work. The author also believes that in many localities cottages and larger dwellings could be advantageously built of concrete, and with a decided gain in durability and comfort.

363. Notable Examples of Concrete Buildings.—Perhaps the best known of all concrete buildings in the United States are the hotels Ponce de Leon and Alcazar, at St. Augustine, Florida, Messrs. Carrere & Hastings, architects.

These buildings, composed entirely of concrete, and exhibiting all the strains to which building material can be subjected, present an example of the almost limitless use to which concrete can be put.

For the construction of these buildings an elevator was built at a central point of the operation, to the full height of the intended building, and as the walls progressed, story upon story, runways were made to each floor, and the concrete, mixed by two capacious mixing machines on the ground level, was lifted in barrels and run off to the place of deposit. At times in the progress of the work 400 pounds of cement were used in the concrete in a single day.

The time transpiring between the wetting of the concrete and the final running in place, even at the fifth story, was not more than ten minutes at any time.

The concrete was composed of 1 part imported Portland cement, 2 parts sand and 3 parts coquina (a shell), the greater part passing through a $\frac{1}{2}$-inch mesh.

The cost of the concrete in place was about $8 a yard, including arches, columns, etc. In plain thick walls the cost was often much less.

In the basement of the Alcazar is a bathing pool 100 feet long, 60 feet wide and 3 to 10 feet deep, all made of concrete. Rising from this pool are concrete columns, 6 feet square at the base and 40 feet high. These columns support concrete beams of 25 feet span, hollowed out in arch form, which support the glazed roof covering the interior court.

364. **The Leland Stanford, Jr., Museum,** at Palo Alta, California, a very large and costly building, is also constructed entirely of concrete. This building was built on the Ransome system—using twisted iron rods imbedded in the concrete to give tensile strength where required.

The following description of this building, written by the architect, Mr. Geo. W. Percy, gives some idea of the method of construction and also of the cost.

This building was designed to have dressed sandstone for the external walls, backed up with brick, and to have brick partitions with concrete floors. Owing to the great cost of stonework, it was decided to build the walls of cement concrete,

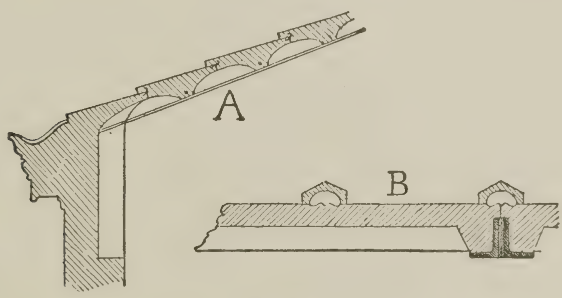

Fig. 240.

colored to match the sandstone used in the other university buildings, and to carry out the classic design first adopted. This led to making the entire structure walls, partitions, floors, roof and dome of concrete, making it, in that respect, a unique building.

Having some knowledge of the disadvantages and defects natural to a monolithic building, such as result from the shrinkage and the expansion and contraction of walls, floor and roof, several new experiments were tried to overcome them, with varying results of success and failure. It was thought to overcome the cracking of walls by inserting sheets of felting through the walls, following the lines of the joints as near as practicable on each side of the windows. The lapping bond of the concrete, however, proved too strong to allow the cracking to follow these joints; in most cases the weakest points were found at the openings, and small cracks appear from window head to sills above.

Joints were formed through the floors about 15 feet apart and in most cases the cracking has followed these joints and been confined to them. To prevent the possibility of moisture penetrating through the walls, and also to render them less resonant, hollow spaces 5 inches in diameter were moulded in the walls within 2 inches of the inside face, and with about 2 inches of concrete between them. These are successful for the primary object, and partially so for the secondary.

The roof being the greatest innovation, and the first attempt known to the writer of forming a finished and exposed roof entirely in concrete, required the greatest care and consideration. The result in form and appearance is shown by Fig. 240, A and B, and may be described as follows: The roof is supported on iron trusses 10 feet on centre, and has a pitch of 20 degrees. The horizontal concrete beams rest on the iron rafters, and with the half arches form the horizontal lines of tiles about 2 feet 6 inches wide, with the joints lapping 2 inches and a strip of lead inserted as shown. Vertical joints are made through the concrete over each rafter with small channels on each side. These joints and channels are covered with the covering tiles shown on drawings, and similar rows of covering tiles are placed 2 feet 6 inches apart over the entire roof, thus forming a perfect representation of flat Grecian tile or marble roof. Notwithstanding the precautions taken, this roof presented several unexpected defects. The most serious proved to be in the Venetian red used for coloring matter and mixed with the cement. This material rendered the covering tiles absolutely worthless, many of them slacking like lumps of lime, and all were condemned and re-made. The same material injured the general surface of the roof, rendering it porous and necessitating painting. The roof over the central pavilion being hidden behind parapets, is made quite flat and covered with asphaltum and gravel over the concrete. This roof, with its low, flat dome, is without question the largest horizontal span in concrete to be found anywhere on earth, being 46 feet by 56 feet, the flat dome having all its ribs and rings of con-

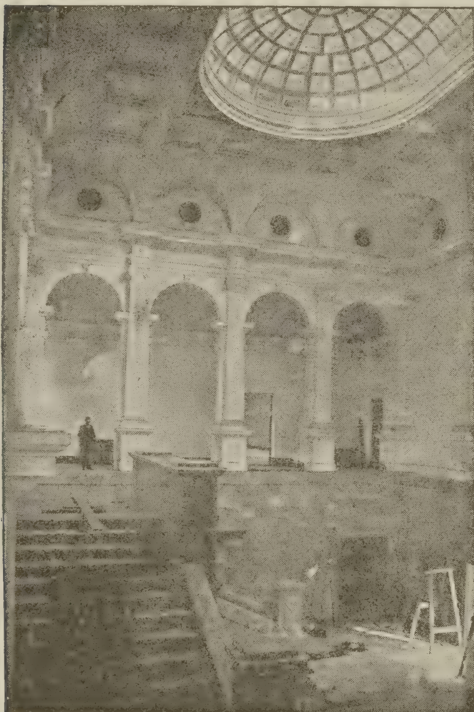

Fig. 241.

crete, with the panels or coffers filled with 1-inch thick glass and weighing about 80,000 pounds.*

This structure covers 21,000 feet and contains over 1,100,000 cubic feet of space. It required about 260,000 cubic feet of concrete, and was completed in seven months from the commencement of the foundations.

The cost of the building per cubic foot, including marble stairs and wainscoting, cast iron window frames and sashes, and other parts to correspond, was about eighteen cents, which is a very low figure for a thoroughly substantial and fireproof building.

Other important buildings which have been executed in concrete in the vicinity of San Francisco are the Girls' Dormitory at the Stanford University (a three-story building completed in ninety days from the time the plans were ordered), the Science and Art building, Mills College; the Torpedo Station on Goat Island, 80x250 feet, and an addition to the Borax Works at Alameda. In the latter the walls, interior columns and all floors are of concrete, and are remarkable for the lightness of the construction and great strength.

All of these buildings were built on the Ransome system.

365. **The Alabama Hotel**, Buffalo, N. Y.—The only large building constructed of concrete in the Eastern States in recent years that the author is acquainted with is the Alabama House, at Buffalo, N. Y., Mr. Carlton Strong, architect. This building is 60x180 feet in size and six stories high, with all walls, floors and partitions built of concrete.

The general plan of the wall and floor construction is shown by Fig. 242, which represents a partial section at level of third floor.

The whole thickness of the wall is 24 inches from top to bottom, the inner portion being 2 inches thick for the whole height; the outer portion is 8 inches thick in first story. and diminishes by 1 inch in each story.

Vertical twisted rods are built in the walls, as shown in the figure, except that they are spaced about 15 feet apart lengthways of the wall. Opposite these vertical rods the withes are 3 inches thick, elsewhere $1\frac{1}{2}$ inches thick. In each withe are built $\frac{1}{4}$ inch twisted rods, extending across the wall, and placed 12 inches apart vertically. At each floor level $\frac{3}{4}$-inch horizontal bars are imbedded in the walls

* Fig. 241 shows an interior view of this dome and the hallway and corridors beneath. All the construction shown in this view is of concrete. In the first story the walls are cased with marble slabs, above they are finished with plaster.

as shown. These twisted steel bars unite perfectly with the concrete and tie the walls together in all directions, while the shape of the wall gives the greatest stability with the least amount of material. It will be noticed that the plan of this wall is very similar to that of the wall shown in Fig. 155. The concrete wall has this advantage over the brick wall, that moisture does not pass through the solid con-

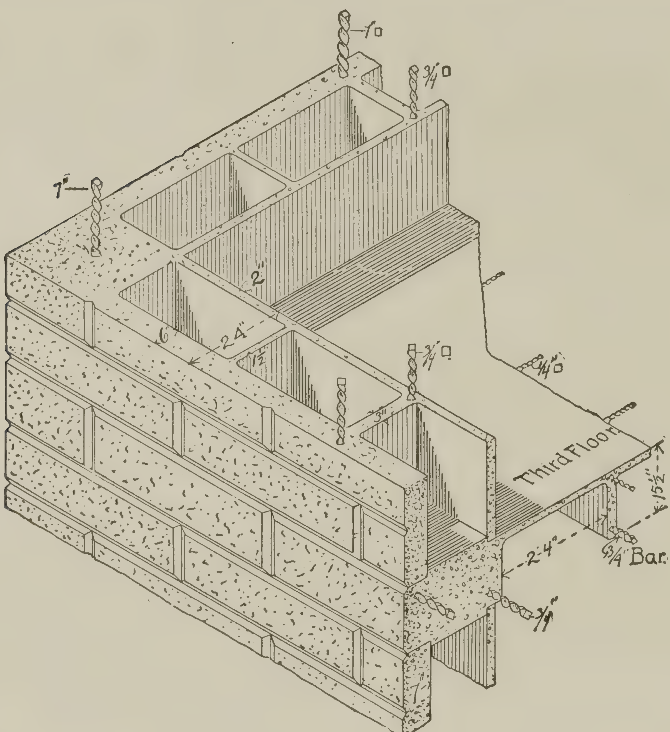

Fig. 242.

crete withes, while there is a possibility of its doing so in brick withes. The spaces in the wall are stopped at each floor level, except that for purposes of smoke flues or ventilation some of them are more or less continuous.

The floors in this building are built on the Ransome system, of concrete with twisted rods. Most of the floors are of the paneled construction shown in Fig. 188 A, although some portions are flat, and of the type shown in Fig. 188.

The partitions are also constructed of concrete, with twisted rods, and, being monolithic, add greatly to the stiffness of the building.

Most of the concrete used in the construction of this building was made in the proportion of 1 part Portland cement to 6 parts aggregates.

The contractors state that the average cost of the wall was twenty-five cents per square foot of outside surface.

This building was commenced in 1894 and completed in 1896.

366. Details of Construction.—The usual method of building concrete walls, piers, arches, etc., is by setting up uprights of 4x4 or 4x6 scantlings at each side of the proposed wall or pier and securing to them boards or moulds, between which the concrete is deposited and rammed. To prevent springing the standards should be bolted together through the wall. For the moulding boards, dressed pine boards $1\frac{1}{2}$ inches thick are recommended; these should be brushed with a hot solution of soap each time before using. After the lower portion of the concrete has set the moulding boards may be removed and used above.

Mr. Ernest Ransome, who has had much experience in the erection of concrete buildings, has patented a movable cribbing, which consists of slotted standards, which, being placed in pairs, one on each side of the wall, and bolted together, hold in position the mould boards. These standards may be raised from time to time as the work progresses without interrupting the filling in of the concrete. In connection with the movable cribbing a series of hoisting buckets, with a traveling crane, is provided for hoisting the concrete. One man stationed upon the wall receives and empties the buckets of concrete as they are hoisted and rams the concrete into place. The crane may be moved around the wall upon the upright slotted standards, so that no scaffolding whatever is required about the wall. It is claimed that the expense of working this apparatus need not exceed a cent per cubic foot of concrete. The first cost is also small.

When mouldings are to be formed on the wall the reverse profile of the mould is stuck in wood and set in its proper place on the mould boards.

Buildings of concrete may be erected very rapidly, as the process of depositing the concrete goes on continuously all around the building, and there is no stone to cut or set, and with proper foresight there need be no waiting for materials.

Concrete Beams or Lintels.—Wherever lintels or beams occur in concrete buildings they should be formed of concrete and twisted rods

or cables in the manner shown in Fig. 243. A beam like that shown, 22 inches wide and 2 feet 10 inches high, was used in a building in San Francisco, where it carries three stories of brick walls and wood floors, with a clear span of 15 feet. The twisted bars were 1 inch square. The three bars near the top were placed only over the supporting posts to give the effect of a continuous girder.

367. Surface Finish.—Most of the concrete buildings constructed previous to 1885 were finished on the outside with plaster or stucco in the manner described for plastering brick walls, Section 354. This finish has not proved very satisfactory, and, moreover, added considerably to the cost of the wall. This unsatisfactory surface finish undoubtedly has had much to do with the limited use of concrete for wall construction.

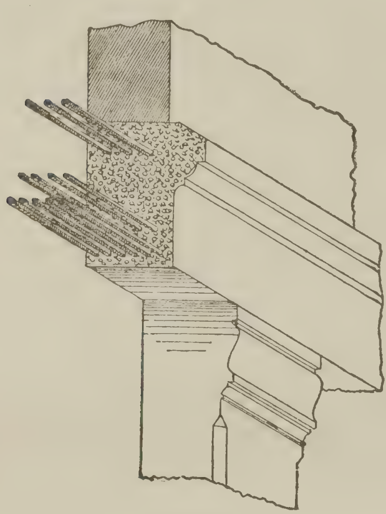

Fig. 243.

It has been demonstrated, however, that the natural face of the concrete can, at slight expense, be finished to closely imitate roughly dressed stonework. Such imitation, moreover, is not, as in most cases, a false pretense or sham, as such surface finish is as natural to concrete as to stone—concrete being in fact an artificial stone.

The usual method of finishing the surface of concrete walls, when it is desired to imitate stonework, is by forming imitation joints in the face of the wall, and either picking or tooling the surface of the blocks thus formed, the former giving the appearance shown on the face of the wall, Fig. 242.

The joints are formed by lightly nailing to the inside face of the moulding boards cleats or strips, moulded or beveled to give the desired form to the recessed joint. After nailing on the strips the inner face of the mould or cribbing will appear something like Fig. 244, the shape and size of the blocks varying to suit the character of the work and the divisions of the wall.

In imitating rough-dressed work the mould is taken from the concrete while it is yet tender, and with small light picks the face of the

stone is picked over with great rapidity, an ordinary workman finishing about 1,000 superficial feet per day. (The first and second stories of the Alabama House are finished in this way.)

For imitations of finer-tooled work the concrete should be left to harden longer before being spalled or cut, and the work should be done with a chisel.

A very neat effect may be obtained by chiseling a margin around the blocks to imitate tooled work, and then picking the centre, as shown in Fig. 245.

If the strips are properly planed and beveled the recessed joints will need no "touching up." Most natural stones (especially granite), bricks and clinkers, if crushed sufficiently fine, make excellent material for this face, but ordinary gravel will do.

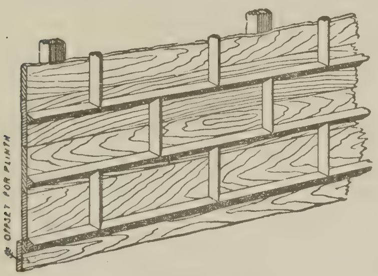

Fig. 244.

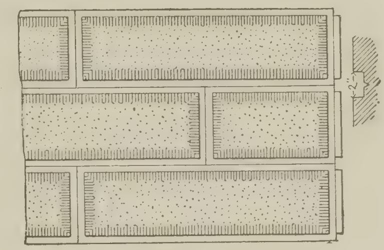

Fig. 245.

Whatever is used, let it be uniform in color and of an even grade. When a very fine and close imitation of a natural stone is required, take the same stone, crush it, and mix it with cement, colored to correspond.

The finer the stone is crushed the nearer the resemblance will be upon close inspection; but for fine work it is generally sufficient to reduce the stone to the size of buckshot or fine gravel.

Rough effective work, excellent in appearance, can be obtained by using the ordinary concrete made with coarse materials. For a finer grade a better material should be used, with aggregates of coarse sand, very small gravel or finely-crushed stone. This fine grade need not extend through the mass of the concrete, but can be applied at the surface only, and by coloring in imitation of various natural stones, the most effective and pleasing results are obtained.

The large bridge in Golden Gate Park, San Francisco, was made with coarse concrete, mixed 1 of cement, 2 of sand and 6 of quartzite rock taken out of adjacent hills and simply broken by hammers without screening, and notwithstanding its coarseness the structure has frequently been mistaken for natural stone by the public.*

368. Making the Concrete.—*Materials and Proportion.*—Concrete for monolithic construction should be made of a good

* Mr. E. L. Ransome.

quality of Portland cement, mixed with clean, sharp sand and a proper proportion of aggregates. As previously stated, almost any natural stone, when broken up, ordinary gravel, or even broken bricks or pottery, may be used for the aggregates. Quartzite rock and granite make the best concrete, but the other materials will answer. Shells were used for the aggregate in the Hotel Ponce de Leon.

The proportions may vary from 1 to 4 to 1 to 8. The proportions used in the buildings mentioned are given in the description.

Mixing.—For small buildings the concrete may be mixed by hand, as described in Section 142, but if very much concrete is required, it will be found much more economical to mix it by a regular mixing machine.

Concrete can also be much more thoroughly mixed in a machine properly constructed for the purpose than is possible by hand, and the strength of the concrete is increased in proportion.

Relative Strength of Mill and Hand-Mixed Concrete.—The opinions of engineers regarding mill-mixed concrete vary considerably. Some claim that it is not so good as hand-mixed, while others would not think of using hand-mixed concrete except on very small work. This difference in opinion is undoubtedly due to the difference in the working of the mills used. With the better class of mills there can now be no doubt that turning the concrete many times greatly increases its strength.

In a series of tests with one mill it was found that the same concrete, which when hand-mixed gave a crushing strength of 25 tons per square foot when one month old, when turned in the mill 500 times gave a crushing strength of over 90 tons when one week old.

Another series of tests furnished the author by Mr. E. L. Ransome gave the following results:

1 part Portland cement, 1 Rosendale, 12 limestone...	1,	2,	3,	4,	8 weeks.
No. 1. Mixed by hand very thoroughly..............	36,	—	36,	54,	68
No. 2. Mixed in mill and turned 500 times	54,	81,	90,	90,	117

There is probably no doubt that in this country, at least, sufficient attention has not been given to the thorough mixing of the concrete, most architects and engineers placing more stress upon the question of tamping than upon that of mixing, whereas the latter is by far the more important of the two.

Some years ago Mr. John Grant, the engineer of the Metropolitan Drainage Canal system of London, demonstrated that the advantage gained by tamping over the untamped concrete did not exceed 40 per cent. Within the past five years Mr. E. L. Ransome has dem-

onstrated that the best mill-mixed concrete and the best hand-mixed concrete vary over 100 per cent. in strength. By means of mill mixing, therefore, it is possible to obtain a better and stronger concrete with a smaller proportion of cement, and consequently at less cost.

Inspection.—Concrete work of all kinds requires the most rigid inspection (see Section 85), as almost everything depends upon the quality of the cement and proper mixing. Unless thorough confidence can be placed in the honesty of the contractor to use the proportion of cement specified, it will be necessary to keep an inspector constantly on the ground to see that the full proportion of cement is

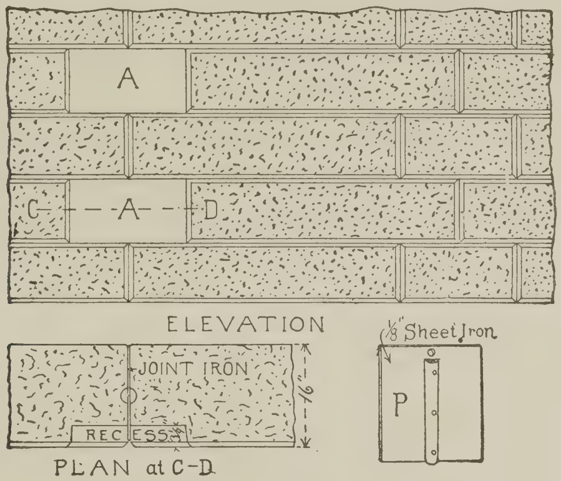

Fig 246.

used. The quality of the cement furnished should also be tested from time to time as the work progresses.

369. Expansion and Contraction.—Concrete diminishes slightly in volume in setting in air, and in monolithic construction this contraction is sufficient to produce cracks throughout the walls and floors. Some method should always be employed, therefore, to allow for expansion and contraction and to make the cracks follow false joints in the work. One method adopted for accomplishing this result in walls is shown by Fig. 246. Through joints are formed at intervals by means of an iron plate, shown at P and on the plan. This plate is pulled up as the wall increases in height, leaving an open joint through the wall. Wherever these joints occur, recesses

are left in every alternate course, as shown at *A A*. These recesses are afterward filled with concrete blocks, formed separately and set in mortar like a stone. If the concrete contracts or settles the break will take place in the joints thus formed, and will not show on the face of the wall.

Window sills should also be put in as slip sills, so that any settlement in the wall will not crack the ends of the sills. If the wall is jointed on the surface, as shown in Figs. 242 or 245, the window heads should be made in the form of a flat arch and a recess left for the key, which should be put in afterward. It is also advisable to have a through joint over the centres of all windows.

When first attempting a concrete building, the architect will do well to consult with some person who has had experience with concrete building as to the best arrangement of overcoming the effects of contraction and expansion.

Concrete walls, with iron ties imbedded, when cracked, however, are not in the bad condition of stone or brick walls without such bond, as the iron ties may be depended upon to prevent spreading or falling.

370. Fireproof Vaults.—One of the rooms in the Leland Stanford, Jr., Museum was designed to be the receptacle of many valuables, and to render it burglar-proof, the floor, walls and ceiling had copper wires imbedded in the concrete not over 3 inches apart, forming a continuous circuit, and designed to strike an alarm bell at the University if any wire should be cut.

This device has also been in use in the U. S. Sub-Treasury in San Francisco for several years; it would seem to be very effective for prison walls and cells.

Even without this electrical safeguard, concrete vaults may be made so as to resist the attempt of burglars for a long time and at a comparatively slight expense.

Iron rods, old iron or steel, may be imbedded in the walls, floor and ceiling to as great an extent as may be deemed necessary; these, being firmly held by the concrete, will be very difficult to cut or remove. Such vaults would also be thoroughly fireproof, and, if made of sufficient thickness, would keep their contents unharmed, even should the building be completely destroyed.

"On one occasion, while building a concrete bank vault in an interior town, several tons of worn-out plowshares were placed in the concrete in such positions as would be most likely to discourage burglars in attempting to cut through the wall." *

* Mr. G. W. Percy, in *Building*

371. Sidewalk Construction.—For constructing sidewalks over areas or vaults, concrete may, in most localities, be used to better advantage as regards quality and economy than any other material or form of construction, as the concrete not only furnishes the necessary strength, but also the finished walk.

Fig. 247 shows a section of monolithic sidewalk construction designed to obtain the maximum benefit from the glass discs built in the walk. No iron whatever is used in the construction of this walk, except for the twisted bars and the columns supporting the beam *A*. As such sidewalks are usually constructed a beam is placed under the wall to support the inner edge of the walk. This beam naturally obstructs much of the light dispersed by the glass discs. In the construction shown the weight of the sidewalk is supported entirely by

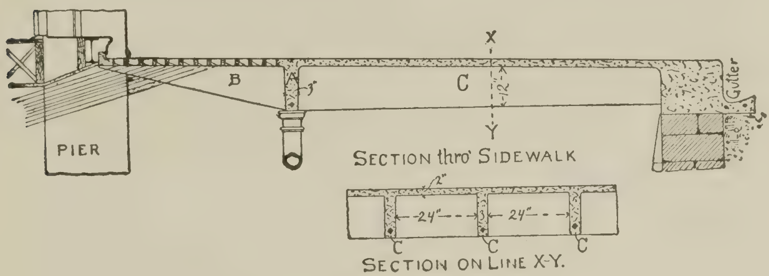

Fig. 247.

the area wall, the beam *A* and the columns beneath. The beams *B* are made to act as cantilevers, $\frac{1}{4}$-inch twisted bars being imbedded in the top of the beams and crossways between the lights. The bars in the top of beams *B* are carried 5 or 6 feet beyond the beam *A*, and the beams *B* are placed opposite those marked *C*. The beams *A* and *C* have $\frac{3}{4}$ or 1 inch bars imbedded near the bottom to furnish the tensile strength.

If necessary, the columns may also be dispensed with by putting trimmer beams opposite the piers to support the beam *A*.

Other Uses for Concrete Construction.—There are various other uses which might be advantageously made of concrete construction, such as foundation and area walls, retaining walls and area steps.

When the foundation walls start from different levels Portland cement concrete may be used with especial advantage, as it is subject to but very little, if any, settlement or compression, and consequently if the settlement of the ground is uniform no cracks will appear in the walls.

It is also claimed that concrete gives a drier basement than stone or brick, and in many localities it should be cheaper. The walls should be built in the manner described in Section 366, using plain boards for the moulds.

For retaining walls concrete-iron construction would appear to be eminently adapted, as there is always a tendency in such walls for the joints to open at the back, or for the upper part to slide on the lower. Both of these tendencies are readily overcome by using Portland cement concrete and twisted iron, and the wall need only be made of such thickness that it cannot be overturned bodily.

Concrete is also well adapted, in many localities, for steps to areas, or in terraced grounds to ascend from one level to another. Such steps are generally more exposed to moisture and dampness, and disintegrate more quickly, if of stone, than in almost any other situation. With concrete steps the dampness simply increases their strength and hardness.

Fig. 248.

Where the ground is firm concrete steps may be built by shaping the ground, then setting up a form for the risers, and filling in the concrete between the form and the ground, the treads being smoothed off with a trowel. By placing $\frac{3}{4}$-inch twisted bars in the angles, as shown in Fig. 248, these steps may be made fully as strong as if built of stone, and more durable.

The thickness of the concrete should be from 2 to 3 inches. On doubtful ground or any ground that is subject to frost, $\frac{1}{4}$-inch twisted bars should be bent to the shape of the steps and built in the concrete, as shown in the figure, to prevent the treads and risers being broken by settlement or heaving of the ground. These smaller bars may be placed from 1 to 4 feet apart, according to the nature of the soil.

Where the ground is not sufficiently firm to sustain the concrete without assistance, a thin sheet of iron may be set up to hold the back of the riser, as shown by the heavy line, and after the concrete riser has been formed the iron can be withdrawn, the earth tamped slightly, and the same iron used for the next step, and so on, step by step.

Test of Concrete Slabs Built on the Ransome System.—The following tests of the transverse and shearing strength

and the resistance to impact of a concrete slab 4 inches thick were made by Prof. Miller, Chief of the Engineering Laboratory of the Massachusetts Institute of Technology, early in 1896:

The slab was 5 feet wide, 14 feet long and 4 inches thick, with $\frac{3}{8}$-inch twisted steel bars 6 inches on centres imbedded near the bottom. The concrete was made of 1 part Alsen cement, 1 part sand and 6 parts broken stone (2 parts passing through a $\frac{1}{2}$-inch ring and 4 parts through a $\frac{1}{4}$-inch ring).

The slab was laid over the tops of four steel I-beams, spaced 4 feet 8 inches apart on centres, thus making a continuous beam of three equal spans. Over the supports $\frac{3}{16}$-inch twisted bars, 3 feet long, were imbedded in the top of the concrete.

The first section was tested by building a brick pier *over its entire area* until a load of 724 pounds per square foot was attained, when the deflection was $\frac{5}{32}$ inch, without cracking. On the middle span a spruce beam, 8x12 inches and 8 feet 4 inches long, weighing 164½ pounds, was dropped five times from a height of 7 feet 10 inches, twice striking in the same spot, without doing any damage.

By means of screw jacks a pressure of 6,200 pounds was applied on an area of about ½x9 inches between two twisted bars without breaking; on increasing the pressure the concrete cracked and failed. Finally a steel beam was laid across the centre of the middle span and a load of 20,700 pounds put on by a jack screw before the concrete cracked, the deflection reaching $1\frac{1}{32}$ inch.

ADDENDA TO FIFTH EDITION.

Since this chapter was written, Concrete Construction has had a notable extention for all kinds of work.

The extent to which the Ransome system, alone, has been used in the construction of buildings and factories, is only partially indicated by the following list of buildings, having walls, floors and partitions of concrete.

Fifteen Story Office Building, Washington, D. C.

St. James Church, Brooklyn, N. Y.

Willard Parker Hospital, New York City.

Court House and Jail, Mineola, Long Island.

Grand Stand, Cincinnati, Ohio.

Six dry kilns and two factories for Singer M'f'g Co., Cairo, Ill.

Twenty four dry kilns, pattern house and oil house, South Bend, Ind.

Four story Refinery for Pacific Coast Borax Co., Bayonne, N. J.

Factory for the Farley Duplex Magnet Co., Jersey City, N. J.

Factory for the Central Lard Co., Jersey City, N. J.

Warehouse for the Pacific Coast Borax Co , Bayonne, N. J.

Two 130 ft. Chimney stacks at South Bend, Ind., and one 100 ft. stack at Jersey City.

The Ransome & Smith Co. give the cost of Factory buildings under their system at 7 cents per cubic foot.

CHAPTER XIII.

SPECIFICATIONS.

372. The specifications for any particular piece of work should be considered as of equal importance with the drawings. The architect should not expect the contractor to do anything not provided for by the plans and specifications without extra compensation, nor to do the work better than the specifications call for. He must therefore be sure that everything which he wishes done is clearly indicated either by the plans or specifications, and that no loopholes are allowed for poor workmanship or inferior materials. The portions of the work to be done by each contractor should also be clearly stated, so that there can be no misunderstanding as to who is to do certain portions of the work. It very often happens that some minor details, such as closing up the windows, protecting stonework, etc., are not properly specified, and the contractors dispute, much to the annoyance of the architect, as to who shall do that part of the work. Such annoyances are largely avoided when the entire contract for the erection and completion of the building is given to one person or firm, but even then it is better to have the duties of the sub-contractors clearly defined.

As a rule, the form, dimensions and quantity of all materials should be fully indicated on the drawings, so that only the kind and quality of the materials and the manner of doing the work need be given in the specifications. General clauses should be avoided as far as possible, as they only cumber the specifications and tend to obscure the really important portions.

The following forms of specifications for various kinds of mason work are given merely as a guide or reminder to architects, and not always to be copied literally. Figures or words enclosed in ( ) may be changed to suit special or local conditions.

Every specification should be prepared with special reference to the particular building for which it is intended.

The use of standard specifications is not recommended, as when such specifications are used the architect is more apt to overlook important points, and the use of such forms, moreover, tends to a lack of progressiveness and a study of the best construction to suit the varying circumstances of different buildings.

The author would recommend to the young architect that before commencing to write or dictate his specifications he make a skeleton, consisting of headings of the different items to be specified, carefully looking over the plans and revising the skeleton until everything seems to be covered and the headings arranged in their proper sequence. The specifications can then be filled out in the manner herein indicated.

GENERAL CONDITIONS.

373. Every specification should be preceded by the general conditions governing all contractors. These may advantageously be printed on a separate sheet and used as a cover to the written specification, and should not be repeated in the latter.

The general conditions used by different architects vary more or less, according to the experience of the architect.

The following form has been used by the author for a number of years with satisfactory results :

General Conditions :—The contractor is to give his personal superintendence and direction to the work, keeping, also, a competent foreman constantly on the ground. He is to provide all labor, transportation, materials, apparatus, scaffolding and utensils necessary for the complete and substantial execution of everything described, shown or reasonably implied in the drawings and specifications.

All material and workmanship to be of the best quality throughout.

The contractor must carefully lay out his work and be responsible for any mistakes he may make, and any injury to others resulting from them.

Where no figures or memoranda are given, the drawings shall be accurately followed according to their scale ; but figures or memoranda are to be preferred to the scale in all cases of difference.

In any and all cases of discrepancy in figures, the matter shall be immediately submitted to the architects for their decision, and without such decision said discrepancy shall not be adjusted by the contractor save and only at his own risk ; and in the settlement of any complications arising from such adjustment, the contractor shall bear all the extra expenses involved.

The plans and these specifications are to be considered co-operative ; and all works necessary to the completion of the design, drawn on plans, and not described herein, and all works described herein and not drawn on plans, are to be considered a portion of the contract, and must be executed in a thorough manner, with the best of materials, the same as if fully specified.

The architects will supply full-size drawings of all details, and any work constructed without such drawings, or not in accordance with them, must be taken down and replaced at the contractor's expense.

Any material delivered or work erected not in accordance with the plans and these specifications must be removed at the contractor's expense and replaced with other material or work, satisfactory to the architects, at any time during the progress of the work. Or in case the nature of the defects shall be such that it is not

expedient to have it corrected, the architects shall have the right to deduct such sums of money as he considers a proper equivalent for the difference in the value of the materials or work from that specified, or the damage to the building, from the amount due the contractor on the final settlement of the accounts.

The contractor will provide proper and sufficient safeguards and protection against the occurrence of any accidents, injuries, damages or hurt to any person or property during the progress of the work, and shall be alone responsible, and not the owner or the architects, who will not in any manner be answerable for any loss or damage that may happen to the work, or any part thereof, or for any of the materials or tools used and employed in finishing and completing the work.

The contractor must produce, when called upon by the architects, vouchers from the sub-contractors to show that the work is being paid for as it proceeds.

Every facility must be given the architects for inspecting the building in safety, such as ladders, scaffolding and gangways, and provision to be made to the architects' satisfaction for protection from falling materials.

The drawings are the property of the architects and must be returned to them before the final payment is made.

The contractor is to keep the building at all times free from rubbish and shavings, and on completon to remove all rubbish and waste material caused by any operations under his charge, clean up the house and grounds, and leave the work perfect in every respect.

EXCAVATING AND GRADING.

374.—The contractor shall visit the site of the building and examine for himself the condition of the lot, and satisfy himself as to the nature of the soil.

[Where this is not practicable the architect should show the present grade of lot by red lines on the elevation drawings, and the nature of the soils should be determined by borings or test pits. See Section 4.]

Loam.—This contractor is to remove the present top soil to the depth of 12 inches from the site of the building and for (20) feet on each side, and stack where indicated on the lot.

Excavate to the depth shown by the drawings for the cellar, areas, coal vault and outside entrance, and for trenches under all walls and piers. All trenches shall be excavated to the neat size as far as practicable, and each shall be leveled to a line on the bottom, ready to receive the foundation. This contractor must be careful not to excavate the trenches below the depth shown by the drawings; should he do so he must pay the mason for the extra mason work thereby made necessary, as under no condition will dirt filling be allowed.

All excavations to be kept at least (12) inches outside the outer face of walls. (See Section 31.)

[Excavations for drains, dry wells, furnace pit, air ducts, etc., to be specified here if required.]

Water.—Should water be encountered in making the excavations, this contractor is to keep it pumped out of the way until the footings are set, unless practicable to drain into sewer.

Stone.—Should a solid ledge be encountered in the excavations, this contractor is to remove the same by blasting or other process, and is to pile the stone where directed on the lot (if suitable for foundation). For removing such stonework an extra sum of (——— cents) per cubic foot of stone excavation will be paid, but no extra payment will be made for removing boulders or loose stones.

Remove from the premises as soon as excavated all material except the loam and such as may be needed for filling about the walls (or grading).

Filling.—When directed by the architect, this contractor shall fill about the walls (with stone, gravel or sand) to within (3) feet (half their height) of the finished grade, and as soon as the first floor joist are set he shall complete the filling to the grade line, tamping the earth solidly every 6 inches. (See Section 87.)

Grading.—Grade the surface of the lot to the level indicated by the drawings (using the loam first removed) and leave in good condition for top dressing (or paving.) (Foundations for walks and driveways.)

[When building on a site formerly occupied by a building, or covered with rubbish, the specifications should provide for the removal of all rubbish, debris, old foundation stone, sidewalk stone and other materials that cannot be used in the new building.]

PILING.

375.—This contractor is to furnish and drive the piles indicated on sheet (1).

All piles shall be of sound (white oak, yellow pine, Norway pine or spruce). They must be at least (6) inches in diameter at the head and (10) inches at the butt when sawn off, and must be perfectly straight and trimmed close and have the bark stripped off before they are driven.*

The piles must be driven into hard bottom or until they do not move more than ½ inch under the blow of a hammer weighing (2,000) pounds, falling (25) feet at the last blow. They must be driven vertically and at the distances apart required by the plans.

They must be cut off square at the head, and, when necessary to prevent brooming, shall be bound with iron hoops.

All piles, when driven to the required depth, shall be cut off square and horizontal at the grade indicated on the drawings by this contractor.

(See Sections 35, 36 and 37.)

CONCRETE FOOTINGS.

376.—All footings colored (purple) on the foundation plan and sections shall be constructed of concrete furnished and put in place by this contractor.

If the trenches are not excavated to the neat size of the footings, or where the concrete is above the level of cellar floor, this contractor shall set up 2-inch plank, supported by stakes or solidly banked with earth to confine the concrete, and these planks are not to be removed until the concrete is (48) hours old.

The concrete shall be composed of first-quality fresh (Atlas) cement, clean, sharp sand and clean (granite) broken to a size that will pass through a 2½-inch ring, and thoroughly screened. These ingredients shall be used in the proportion of 1 part

* This latter clause is not always required.

cement, 2 of sand and 4 of stone, and mixed each time by careful measurement, in the following manner: On a tight platform of plank spread four barrows of sand, and upon this two barrows of cement. Thoroughly mix the two dry, and then throw on eight barrows of broken stone and work over again; then work thoroughly and rapidly with shovels while water is being turned on with a hose, until each stone is completely covered with mortar. No more water to be used thah is necessary to unite the materials. As soon as the concrete is mixed it is to be taken to the trenches and dumped in layers about 6 inches thick, and immediately rammed until the water flushes to the top. The next layer must be put on before the preceding one becomes dry, and the top be well wet before putting in the new layer. The stone footings shall not be put on the concrete until it is two days' old. (See Sections 140, 145.)

[On large and important work the specifications should also provide for testing the cement. (See Section 125.) The above quantities are as much as should be mixed at one time.]

SPECIFICATIONS FOR STONEWORK.

377.—Footings.—*Supported on Piles.*—The pile capping to be of even split granite blocks (16) inches thick from ——— quarries, to be of such size that no stone will rest on *more than three* piles, and to be bonded as shown on special drawing. Each and every stone is to be carefully wedged up with oak wedges on the head of each pile to secure a firm and equal bearing, and are to butt closely together.

Dimension Footings.—The footings under all outside foundation walls are to consist of dimension stone from the ——— or ——— quarries, of the width shown on the section drawings and (12) inches thick. To have fair surfaces top and bottom, and to be bedded and puddled in cement mortar. No footing stone to be less than (3) feet long.

Rubble Footings.—Build the footings under (all other) foundation walls of the width and thickness shown by section drawings, of ——— stone. The stone to be heavy rubble, each stone to be of the full thickness of the footing course, at least 2 feet 6 inches long, and not more than two stones abreast in the width of the wall; there shall also be one through stone, the full width of the footings, every (6) lineal feet. Each stone is to be solidly bedded and puddled in cement mortar, and all chinks between the stones are to be filled solid with mortar and spalls.

378.—Foundation Walls.—*Block Granite or Limestone.*—Build the foundation walls colored (blue) on plans to the height and thickness shown by section drawings, of sound, even, split granite (limestone) blocks to average (3) feet in length, (18) inches wide and to be not less than (12) inches in height. To be laid with a good bond in regular courses, as near as can be, and bonded with one through stone in every (10) square feet of wall

The stone to be laid in cement mortar, as described elsewhere, all chinks and voids to be filled with slate or (granite) spalls and mortar, to show a good straight face where exposed in the basement, and the joints to be neatly pointed with the trowel. All walls must be built to a line both inside and outside, and all angles to be plumb. (Inside face of wall to be hammer-dressed.) Top of wall to be carefully leveled for the superstructure, with heavy stones at each corner. Leave holes in wall for drain, gas and water pipes.

Rubble Walls.—Build the foundation and basement walls colored (gray) on plans to the height and thickness shown on section drawings, of ——— stone rubble. To be of selected, large size, first quality stone, laid to the lines on both sides, well fitted together, and all voids filled solid with spalls and mortar. Each stone to be firmly bedded and cushioned into place, and all joints shall be filled with mortar. At least half of the stones are to be two-thirds the width of the wall, and there shall be one through stone to every (10) square feet of wall. The larger part of the stones shall be not less than (2 feet) long, (16 inches) wide and (8 inches) thick. The wall to be laid in courses about (18 inches) high and leveled off at each course.* (Each stone shall have hammer-dressed beds and joints, and the face of the stone showing on the inside of the wall shall be coarse bush-hammered.†) The wall to be built plumb and carefully leveled on top to receive the superstructure.

Cementing Outside of Wall.—As soon as the wall is completed the contractor is to rake out all loose mortar in the outside joints and plaster the entire outside of the wall (except where exposed in areas) with Dyckerhoff Portland cement mortar not less than ½ inch thick. The mortar to be mixed in the proportion of 1 to 1. Area walls to have the joints raked out and pointed with cement mortar, and a false joint of red cement mortar run with a jointer and straight-edge. The trench is not to be refilled until the wall has been plastered at least twenty-four hours.

Basement Piers.—All piers colored (blue) on basement plan to be built of ——— stone, and each stone shall be of the full size of the pier ‡ laid on its natural bed, and the top and bottom of each stone to be cut so as to form joints not exceeding ½ inch in width. All four sides of pier to be rough pointed and all corners to be pitched off to a line. The top stone to be dressed to receive the iron plate resting on the pier and each stone to be solidly bedded in cement mortar as specified elsewhere.

Mortar.—All stone masonry above referred to shall be laid in mortar composed of perfectly fresh (Rosendale) cement, ——— brand, mixed in the proportion of 1 part cement to (2) parts of clean, sharp sand. The sand and cement shall be mixed dry in a box, then wet, tempered and immediately used. (See Section 128.) No mortar that has commenced to set to be used on the work.

379.—External Stone Walls.—*Rubble.*—Build the external walls (in first story) of rubble from the ——— quarries. To be laid random, with hammer-dressed joints, and the outside face split so that the projection shall not exceed 2 inches. The stones to be laid on their natural bed, with good vertical bond, and to be one through stone in every 10 square feet of wall. All stones showing on the exterior to be selected from the largest in the pile, and as few spalls to be used as possible. Every stone to be well bedded in mortar, made of 1 part (Rosendale) cement and (2) parts clean, sharp sand, and all joints and chinks filled solid with mortar and spalls. All inside joints to be smoothly pointed with the trowel as the wall is built. After the wall is built the joints on the outside are to be raked out and filled with cement mortar, and a false joint of red Portland cement mortar run with a jointer and straight-edge, in imitation of broken ashlar.

* This is unnecessary in ordinary foundations for dwellings.

† Only required in places where a neat and extra strong wall is required. This is expensive work.

‡ Or, in courses varying from 8 to 12 inches in height, every other course to be the full size of the pier and the intermediate course to consist of two stones, each one-half the size of the pier. Each stone to be laid on its natural bed, etc.

Field Rubble.—The external wall of (first story) is to be faced with round field stones, selected for their color, and the moss and lichens left on. The stones to be fitted together according to their size and without spalls. The back and sides to be split with the hammer where necessary to give a bond, and the stones to have their long axis crossways of the wall and to be laid in cement mortar. The wall to be backed up with split-face rubble carefully bonded to the facing.

CUT STONEWORK.

380.—*Granite.*—All trimmings colored blue on the elevation drawings to be of (Quincy) granite. The stock to be carefully selected and free from all natural imperfections, such as mineral stains, sap or other discolorations; to be of an even shade of color throughout, so that one stone shall not look of a different shade from another when set in place.

The face of sills, caps, quoins and water table, where so indicated on the elevation drawings, to be pitched face, with 1-inch angle margin on the quoins and water table. All steps and thresholds to be hammered work, six-cut, and the balance of the trimmings to be best eight-cut work.

Sandstone.—All trimmings shown by brown color on the elevation drawings to be of best quality selected (Cleveland) buff sandstone, of uniform color and hardness, free from sand holes and rust, and cut so as to lay on its natural bed when set in the wall. All stone trimmings thus shown are to be worked in strict accordance with the detail drawings, with true surfaces and good sharp, straight lines; and all stone belts, unless otherwise provided for, are to have a bearing upon the walls of at least (6) inches, and the projecting courses to have a bearing of 2 inches more than the projection. All exposed surfaces of the sandstone are to be carefully tooled, (rubbed) or (crandalled), the workmanship being regular and uniform in every part and done in a skillful manner. All mouldings to be carefully fitted together at the joints, and no horizontal or vertical joint to exceed $\frac{3}{16}$ of an inch. All return heads at the angles, etc., are to be at least (12) inches. No patching of any stone will be allowed.

[Ordinary soft sandstones, or "freestones," are not suitable for steps and door sills, which should be either of granite or some hard sand or limestone.]

Ashlar.—The (south) and (west) walls of the building where exposed above the (water table) are to be faced with coursed (broken) ashlar of the same stone as specified for the trimmings. The ashlar to be in courses (12) inches high, except as otherwise shown on elevation drawings, and to have plumb bond wherever practicable. (The surface of the quoins to be raised 1 inch from the face of the wall, with beveled or rusticated joints, and the faces of the stones to be rusticated in a skillful manner. Each quoin to be (16)x(24) inches, reversed as shown on drawings.) The balance of the ashlar to be rubbed to a true surface, without wind, cut to lie upon its natural bed, and for $\frac{3}{16}$-inch joints. No stone to be less than 4 inches thick, and at least one jamb stone to each opening to extend through the wall. All mullions 16 inches or less in width to be cut the full thickness of the wall.

The contractors, both for the granite and sandstone, are to do all drilling, lewising, fitting and other jobbing required for setting the stone or to receive iron ties, clamps, etc., and are to provide all patterns necessary and required for the execution of the work.

Setting Stonework.—[The specifications should distinctly state who is to set the stonework. If the stonework consists of a few trimmings only it will be cheaper for the brick mason to set it, but if there is much stonework it should be set by the stone mason.]

All stonework shown by blue or brown color on the elevation drawings, and as previously specified, is to be set in the best manner by this contractor in mortar mixed in the proportions of 2 parts of (Rockland) lime mortar and 1 part fresh (Rosendale) cement. The cement to be mixed with the lime mortar in small quantities and in no case shall any be used that has stood over night. (For setting limestone and marble see Section 208.)

As the stone is delivered at the building the mason will accept the same and be held responsible therefor until the full completion of his contract; any damage that may occur to any stone, whether on the ground or in the building, during the said period, shall be made good at his own expense and to the satisfaction of the architect or superintendent.

The mason must call upon the carpenter to box or otherwise protect by boards all steps, mouldings, sills, carving and any other work liable to be injured during the construction of the building.

Every stone to be carefully set, joints left open under centre of sills and at the outer edges of all stonework, and all stones to be uniformly bedded, joints kept level and plumb and of uniform thickness. The mason is to provide derricks and all other apparatus necessary to set the stone properly, and is to carry on the work so as not to delay the other mechanics. Where the stone is backed up with brick the stone shall not be set more than two courses ahead of the backing.

Anchors and Clamps.—This contractor is to provide all necessary iron anchors and clamps (which are to be galvanized or dipped in tar) for securing the stone as herein specified or as directed by the superintendent.

Each piece of ashlar 12 inches or more in height is to have one iron anchor extending through the wall, and when exceeding 4 feet in length two clamps are to be used. (Broken ashlar will be bonded by through stones, one to every 10 square feet of wall.) Also anchor all projecting stones, corbels, finials, etc., with iron anchors satisfactory to the superintendent. All coping stones and other horizontal string courses or cornices, where so indicated by notes on the drawings, are to be clamped together.

Cleaning and Pointing.—After all the stonework is set complete (and the roof is on) the mason shall scrub down with muriatic acid and water, using a stiff bristle brush, all stonework, rake out all joints to the depth of 1 inch and repoint with Portland cement and (Clinton) red, well driven into the joint and rubbed smooth with the jointer with half round raised joint as per marginal sketch. (It will be well to show in margin the kind of joint desired; see also Section 209).

The entire work to be left clean and perfect on completion of the contract.

SPECIFICATIONS FOR BRICKWORK.

381.—This contractor is to furnish all materials, including water, and all labor, scaffolding and utensils necessary to complete the brickwork indicated by red color on the plans and sections, and as shown by the elevations and as herein specified.

Face Work.—*Pressed Brick.*—The exposed surfaces of the building (on south and east elevations), including the chimneys, to be faced with (St. Louis) pressed brick like the sample in architect's office ; all to have good sharp edges and to be of uniform size and color.

Moulded Brick.—Furnish all moulded brick shown on elevation drawings and as indicated by numbers (which refer to ———'s catalogue). These brick to be as near the color of the pressed brick as can be obtained, and laid to give as even lines as possible Furnish octagon brick for the external angles of bays and circular brick of proper curvature for the circular bay (or tower).

Stock Brick.—The exposed surfaces of the brickwork (on west elevation) to be of best quality dark red stock brick, with good sharp corners and square edges.

Common Brick.—The balance of the exposed brickwork to be of selected, even-colored common brick, as nearly uniform in size and color as can be obtained, and carefully culled.

All face brick to be laid in the most skillful manner (from an outside scaffold) in colored mortar, as specified elsewhere. Each brick to be dipped in water before laying ; each edge of the brick and down the middle to be butted, and all vertical joints to be filled solid from front to back. The brick to be laid with plumb bond and bonded to the backing with a diagonal header to every brick in every (fifth) course. [Or bonded with the Morse tie, one tie laid over every brick in every fourth course.] In piers only solid headers to be used.

All courses to be gauged true, and all joints to be rodded (or struck with a bead jointer. See Section 237).

The returns of pressed brickwork must be carefully dovetailed into the common brickwork or bonded by solid headers.

Ornamental Work.—All brick cornices, belt courses, arches, chimney tops and other ornamental brick features of the building must be laid up in the most artistic and substantial manner, according to the scale and detail drawings. All arches to be bonded and the bricks cut and rubbed so that each joint will radiate from the centre. (Arch brick are often specified for first-class work in large cities.)

Common Brickwork.—All other brickwork to be laid up with good hard-burned (the best merchantable) common bricks, acceptable to the architect, in mortar, as specified elsewhere.

All brick shall be well wet, except in freezing weather, before being laid.

Each brick shall be laid with a shove joint in a full bed of mortar, all interstices being thoroughly filled, and where the brick comes in connection with anchors each one shall be brought home to do all the work possible.

Up to and including the fourth story every fourth course shall consist of a heading course of whole brick, extending through the entire thickness of the wall or backing ; above the fourth story every sixth course shall be a heading course.

All mortar joints, where the wall is not to be plastered, shall be neatly struck, as is customary for first-class trowel work. All courses of brickwork shall be kept level, and the bonds shall be accurately preserved. When necessary to bring any courses to the required height, clipped courses shall be formed (or the bricks laid on edge), as in no case shall any mortar joints finish more than ½ inch thick. All brickwork shall be laid to the lines, and all walls and piers must be built plumb true and square. Walls to be carefully leveled for floor joist.

All cut stone shall be backed up as fast as the superintendent shall direct, and the brick mason shall build in all anchors that may be furnished by the contractor for the cut stonework, or by the carpenter or iron contractor.

All partition walls to be tied to the outside walls by iron anchors (furnished by this contractor), $\frac{3}{16}$x$1\frac{3}{4}$ inches in section and (3 feet 6 inches) long, built into the walls every (4) feet in height.

When openings or slots are indicated in the brick walls, the size and position of the same shall be such as the superintendent shall direct, unless otherwise shown. This contractor shall leave openings to receive all registers that may be required in connection with the heating or ventilating system.

Firmly bed and fill in around all timbers, point around all window frames, inside all staff beads and window sills, and wherever required, and bed all wall plates in mortar on the brickwork.

Protection.—This contractor shall carefully protect his work by all necessary bracing, and by covering up all walls at night or in bad weather. (He shall protect all mason work from frosts by covering with manure or other materials satisfactory to the superintendent.

The top of all walls injured by the weather shall be taken down by this contractor at his expense before recommencing the work.

Hollow Fire Clay Brick (for buildings of skeleton construction).—All brick used in connection with the spandrels above the first story on all elevations, together with all backing required in connection with the stone or terra cotta work above the (sixth) story floor beams, shall consist of first quality hard-burned fire clay, hollow brick, equal in quality to sample in the architect's office. Each brick shall be laid with a shove joint and the work well bonded. The inside surface of the wall to be left smooth, true and ready for plastering.

Mortar.—*Cement Mortar.*—All brickwork below the grade line and the last five courses of chimneys and parapet walls shall be laid in mortar composed of 1 part fresh (Rosendale*) cement and (2) parts clean, sharp bank sand, properly screened, mixed with sufficient water to render the mixture of proper consistency. Care must be taken to thoroughly mix the sand and cement dry, in the proportions specified, before adding the water. The mortar shall be mixed in small quantities only, and in no case shall mortar that has commenced to set or stood over night be used. (See Section 128.)

[In Colorado, and possibly in some other localities, a gray hydraulic lime is obtained, which answers about as well as cement for foundation walls.]

Lime and Cement Mortar.—All common brickwork in (first and second) stories to be laid in mortar composed of (3) parts of lime mortar, having a large proportion of sand and 1 part of fresh (Utica) cement. The lime mortar to be worked at least two days before the cement is added, and only small quantities of cement to be mixed at a time (see Section 131.)

Lime Mortar.—The balance of the common brickwork to be laid in mortar composed of fresh-burned (Rockland) (Missouri) lime and clean, sharp sand, well screened. (No loam to be used.) The lime and sand to be mixed to make a rich

* Or any of the cements described in Section 111.

mortar, satisfactory to the architect. Lime that has commenced to slake shall not be used.

Colored Mortar.—All face brick to be laid in mortar composed of lime putty and finely-sifted sand, colored with (Pecoria) or (Peerless) mortar stains; colors to be selected by the architect.

Grouting.—All brick footings and the piers in basement must be grouted in every course and flushed full with cement mortar, as specified above.

Cement Plastering.—The outside of all brick walls that come in contact with the earth shall be smooth plastered by this contractor, from bottom of footings to grade line, with (Atlas) Portland cement mortar, mixed in the proportion of 1 to 2, and of an average thickness of ½ inch.

Plaster the top of all projecting brick belt courses, and the tops of fire walls, where not otherwise protected, with the same kind of mortar, being careful to make a neat job. (See Section 240.)

Relieving Arches.—Turn three rowlock relieving arches over all door and window openings behind the face arch or lintel. These arches to have a brick core, and to spring from beyond the ends of wood lintel.

Chimneys.—Build all chimneys and vent flues as shown by drawings, and top out as shown on elevation drawings.

All withes to be 4 inches thick, well bonded to the walls, and the flues to be carried up separately to the top. Plaster the inside of all flues (unless provided with flue lining) from bottom to top with (Portland cement) mortar, and plaster the outside of the flues where they pass through the floors.

Slides (slanting boards) must be put in each flue at the bottom, with an opening above to carry out the mortar droppings, and on completion of the chimneys the flues must be thoroughly cleaned out and the openings bricked up.

All brick chimney breasts to be built plumb, straight and true, and all corners square.

Build rough openings for fireplaces (with ½x2-inch iron arch bars, turned up 2 inches at the ends) and turn-trimmer arches to the same 2 feet wide on wooden centres furnished and set by the carpenter.

Build the ash pits under grates, as shown by plans, and provide and set a cast iron ash pit door and frame in each pit where shown or directed.

Flue Lining.—Furnish and set in (the range and furnace flues) 8x12-inch fire clay flue linings to start (2 feet) below the thimble and continued to the top of flue. The lining to be set in rich lime (cement) mortar, with joints scraped clean on the inside.

Thimbles.—Provide and set in all flues, except grate flues, (sheet) iron thimbles, 8 inches in diameter in furnace flue and 6 inches elsewhere, to be set 2 feet below the ceiling unless otherwise directed. Furnish bright tin stoppers for all thimbles except for (range and furnace.)

Cold Air Duct.—Excavate for and build the cold air duct and foundation for furnace as shown by drawings of hard-burned brick, laid in (Rosendale) cement mortar, and plastered smooth on the inside; also plaster the bottom of duct and furnace pit with cement mortar, on a 2-inch bed of sand. Cover the top of the air duct with (2½) inch flagstone with joints neatly fitted and the edges cut true and square. The flagging to be furnished by (this) contractor

Fire Walls.—This contractor shall furnish and set, in Portland cement, salt-glazed tile copings on all fire walls not covered by stone or metal copings. The copings are to be 2 inches wider than the walls and to have lapped joints.

Ventilators.—Leave ventilating openings in the foundation walls and between roof and ceiling joist, where shown on drawings, and put cast iron gratings in the openings.

Cutting and Fitting.—This contractor shall do promptly and at the time the superintendent so directs, all cutting and fitting that may be required in connection with the mason work by other contractors to make their work come right, and shall make good after them.

Setting Ironwork.—This contractor is to set all iron plates resting on the brickwork, and all steel beams supporting brick walls; also all iron lintels, tie-rods and skewbacks used in connection with brick arches or over openings.

All such work will be furnished at the sidewalk by another contractor, and this contractor shall set the same in such position and at such height as the superintendent shall direct. All plates to be solidly bedded, true and level, in 1 to 2 fresh (Atlas) Portland cement mortar; the brickwork to be brought to such a height that the bedding joint shall not exceed ½ inch.

[Where there is but little ironwork it is sometimes desirable to specify that the brick mason shall assist the carpenter in setting iron columns and steel beams. Large contracts for iron and steel work are generally erected by a special contractor. All ironwork coming in connection with the stonework should be set by the same contractor that sets the stonework.]

Setting Cut Stone.—The contractor for the stonework will set all belt courses, stone arches, coping, steps and other stone where fitting may be required, but this contractor shall set all single caps, sills and bond stones, the stone being delivered at the sidewalk. All such pieces of stone to be set in the best manner, in mortar as specified for the face brick. Sills to be bedded only at the ends.

Setting Terra Cotta.—This contractor shall set all terra cotta work, indicated by pink color on the elevation drawings, in the best manner, in the same kind of mortar as is specified for the pressed brickwork. All terra cotta work that does not balance on the wall, or where indicated on the drawings, shall be securely tied to the backing by wrought iron anchors, of approved pattern, thoroughly bedded in cement mortar. (See also specifications for terra cotta work.)

Cleaning Down and Pointing.—On completion of the brickwork this contractor is to thoroughly clean the face brick, using dilute muriatic acid and water, applied with a scrubbing brush. Care must be taken not to let the acid run over the cut stone. (Some stones are injured by acid and must be cleaned with water only.) While cleaning down this contractor is to point up under all sills, and wherever required to leave the wall in perfect condition.

[Where there is little cut stonework the cleaning and pointing of it may also be included in this specification.]

Outhouses—[Customary only in Western cities.]—Build the outhouses and ash pit on the rear of the lot, as shown by plans, of hard-burned brick. Arch over the ash pit and give a heavy coat of (Portland) cement mortar. Leave an opening in

the top for putting in ashes and provide an iron ring and cover for same. Furnish and set on the alley side at the grade a cast iron ash pit door and frame.

Rubbish.—Clean out all boards, plank, mortar, brick and other rubbish caused by the brick masons, and remove from the building and grounds, on completion of the brickwork or when directed by the superintendent.*

Brick Paving (for yards.)—Pave the yards and areas where so indicated on plans with good hard (vitrified) paving bricks, sound and square, laid flat, herring-bone fashion, on a bed of sand from (4) to (6) inches deep.

[The necessary depth of sand varies with the quality of the soil, a stiff clay requiring the most sand ; on such soils a bed of furnace cinders, etc., may be used to advantage before the sand is put down.]

After the bricks are laid and graded (which should be about 1 inch in 10 feet) to drain the water to the grade or to its proper outlet, the entire surface must be covered with sand, which must be swept over the bricks until the joints are thoroughly filled.

[For a better pavement the joints should be grouted in liquid cement mortar and the sand spread over afterward. Where extra thickness of wearing surface is required the bricks may be laid on edge and grouted or covered with sand as above.]

Where brick gutters are shown the bricks are to be laid lengthways and the joints grouted in cement mortar.

(For requirements for paving brick for streets and driveways, see Section 226.)

SPECIFICATIONS FOR LAYING MASONRY IN FREEZING WEATHER.†

382.—Only in case of absolute necessity shall any masonry be laid in freezing weather. (See Sections 139 and 239.)

Any masonry laid in freezing weather must not be pointed until warm weather in the spring. If necessary, masonry may be laid in freezing weather, provided the stone or brick are warmed sufficiently to remove ice from the suface and the mortar is mixed with brine made as follows: Dissolve 1 pound of salt in 18 gallons of water when the temperature is at 32° F., and add 1 ounce of salt for every degree the temperature is below 30° F., or enough salt, whatever the temperature, to prevent the mortar freezing.

SPECIFICATIONS FOR FIREPROOFING.‡

(HOLLOW TILE SYSTEM.)

383.—The following specifications are intended to include the fireproofing of all the steel in the building, the filling in between the beams forming floors and roof, and the concreting over the same to the top of the floor strips. Also the covering of

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* If in the general conditions this paragraph may be omitted.

† Baker's Treatise on Masonry Construction.

‡ Modeled after the specification for the Fort Dearborn Building, Chicago; Messrs. Jenney & Mundie, architects.

all columns, both those standing clear and those partly incased in the walls. Also the building of all tile partitions and tile vaults, and the walls of pent houses on the roof.

This contractor shall furnish all material, including the mortar for setting the same, and shall do all his own hoisting and set all the work in a thorough, substantial and workmanlike manner, to the satisfaction of the superintendent.

Mortar.—All work shall be laid in mortar composed of 3 parts of best fresh lime mortar and 1 part best (Louisville) cement, thoroughly mixed together just before using. Said lime mortar shall be composed of fresh-burned lime and clean, sharp sand in proportions best suited to this work. (For partitions Acme cement plaster may be used. See Section 344.)

Floors.—All floors shall be constructed of flat arches (of porous or semi-porous tile, end-method construction*) set in between the beams and of a shape that will give a uniform flat ceiling in the rooms below. The bottoms and projections of all beams and girders must be protected by projecting parts of tile or by separate beam slabs. In laying the floor arches every floor joint shall be filled full over its entire surface from top to bottom. No joints to exceed $\frac{3}{16}$ inch in thickness.

No clipped or broken tiles will be allowed in the arches, and no cutting of arches will be permitted except where absolutely necessary and under the approval of the superintendent. All the arches must be formed to fit the various spans between floor beams, and in all cases special patterns of voussoirs or keys must be moulded and set where it is impossible to set the regular form.

All floor arches, ten days after they are laid, and before they are concreted, shall be subject to a test of a roller, 15 inches face, and loaded so as to weigh 1,500 pounds, rolled over them in any direction.

[This test is only intended to provide against poor workmanship and improper setting of the tile. If any system whose strength has not been fully demonstrated is to be used, it should be subjected to a more severe test. See Section 299.]

Columns.—All columns shall be covered with (porous) column tile held by metal clamps, both in horizontal and vertical joints. These column protections shall be so made as to conform with the city ordinance.

[Where the city ordinance is not sufficiently strict on this point, the specifications should be more definite as to the shape of the tile. See Section 318.]

Roof.—The roof shall be constructed in the same way as the floors, except that the top of the tile shall be flush with the beams and the soffits may be segmental, with raised skewbacks.

Partitions.—Build all partitions shown on the several plans of (porous, semi-porous or dense) hollow tile, 4 inches thick in the first and second stories and 3 inches thick in all other stories except the hall partitions, which are to be 4 inches thick throughout the building.

In glazed partitions the lower parts and all parts other than the sash and frames shall be of tile.

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* This clause is not in the Fort Dearborn specification.

The tiles shall be set breaking joints and to be tied with metal ties or clamps.

Furring for False Beams and Cornices.—This contractor is also to furnish and put in place tile furring for the cornice and false beams in the (bank and assembly hall), to be of profiles and sections as shown by drawings. (See Section 349.)

The cove and ceiling pieces of the cornice, and all parts of the beams, to have holes cast for bolts, spaced not over 12 inches apart and at least two bolts for each piece. The furring to be properly and securely mitred at angles and all to be properly bedded, with close joints, in mortar as specified above.

All suspended pieces to be substantially fastened in place by $\frac{1}{4}$-inch diameter T-head bolts, spaced not over 12 inches apart, with nuts and washers to each.

(Or, all furring for cornices and false beams will be put up by the contractor for plastering.)

Wall Furring.—Fur the outside walls in finished portions of basement with 3-inch (porous, semi-porous or dense) tile so as to form a vertical and true surface for tiling. The tiles to be set with the hollow spaces vertical, and to be securely fastened to the wall by flat-headed spikes.

Miscellaneous.—All tile work shall be straight and true.

All tiles of every kind must be thoroughly burned and free from serious cracks or checks, or other damages, and shall be laid in a proper and workmanlike manner.

No centres to be lowered until the mortar has set hard.

All structural steel on which the strength of the building depends in any way, including wind bracing, shall be protected by fireproof covering of approved shape and substantially fixed in place.

All tilework to be left in suitable condition for plastering.

Concreting.—This contractor shall fill in on top of the floor arches with concrete composed of 1 part (natural) cement mortar and 4 parts of screened boiler cinders, to be leveled off at the top of the highest beams or girders, and after the floor strips are set by the carpenter to be filled in between said strips with the same concrete pressed down hard with a reasonably true surface $\frac{1}{8}$ inch below the top of the strips.

All damage to tile work to be repaired before the concrete is laid.

Roof.—This contractor shall cover the surface of the roof tiles with 1 to 3 (natural) cement mortar of sufficient thickness to come $\frac{3}{4}$ inch above the top flanges of beams and girders, and to give the desired pitch to the roof, with a reasonably uniform surface.

[If the tops of the tiles are more than $\frac{3}{4}$ inch below the tops of the girders, concrete may be used for filling to top of girders and $\frac{3}{4}$ inch of mortar applied above.]

Outside Walls.—The outside walls of pent house on roof to be built of (4-inch) hard-burnt wall tile, clamped together, and set in mortar as above specified. Every joint, both vertical and horizontal, to be thoroughly filled over its entire surface with mortar, and all outside joints to be struck in a neat and workmanlike manner.

This contractor shall give a written guarantee that the outside face of these tile will stand the weather for (five) years dating from the completion of the wall, and agree to replace any tile injured by the weather, either in winter or summer during said period, promptly and at his own expense.

SPECIFICATIONS FOR TERRA COTTA TRIMMINGS.*

384.—*Material.*—This contractor shall furnish and set wherever called for on drawings terra cotta to exactly match in color the sample submitted, all in strict accordance with detail drawings. Material for all terra cotta to be carefully selected clay, left in perfect condition after burning, and uniform in color. All pieces to be perfectly straight and true, and with mould of uniform size where continuous. No warped or discolored pieces will be allowed. This contractor to furnish a sufficient number of over pieces, so as to avoid all delay.

Modeling.—All work shall be carefully modeled by skilled workmen, in strict accordance with detail drawings, and models shall be submitted for architect's approval before the work is burned. No work burnt without such approval will be accepted by the architects unless perfectly satisfactory.

Mortar.—All mortar used for exposed joints in terra cotta work shall be composed of lime putty, colored with (Pecora) or (Peerless) mortar stains to match the mortar used for pressed brickwork.

Ornamental Fronts, Belt Courses, Bands.—This contractor shall furnish and set all ornamental terra cotta, belt courses and bands, as shown on elevations or sections or where otherwise indicated, in strict accordance with detail drawings. All terra cotta work to be secured to the ironwork in the most approved manner, with substantial wrought iron or copper anchors, and thoroughly bedded in cement mortar. All horizontal joints to have lap joints. All projecting courses to have drips formed on under side.

Caps and Jambs, Sills.—All caps and jambs where indicated as terra cotta will be constructed in strict accordance with detail drawings. All sills and belt courses to have countersunk cement joints as directed by the superintendent. All projecting sills to have drips formed on under side and all sills shall be raggled for hoop iron, which shall be bedded by this contractor in cement mortar.

Terra Cotta Mullions.—All ornamental mullions of terra cotta to be secured to metal uprights in approved manner, and well bedded and slushed with cement mortar.

Cornice.—This contractor shall construct the cornice in strict accordance with detail drawings, with sufficient projection through walls and approved anchorage to the metal work to make them thoroughly secure. This contractor to furnish all necessary anchors. Form raggle in cornice as shown for connection of gutter, this raggle to be on face of terra cotta. Leave openings in cornice for down-spouts as shown.

Anchors.—This contractor shall furnish all anchors of substantial wrought iron or copper, for the proper support and anchoring of all terra cotta used in his work. All terra cotta to be drawn to tight and accurate joints to entire satisfaction of the superintendent. All terra cotta must fit the supporting metal work exactly.

Cutting and Fitting.—This contractor shall do all fitting necessary to make his work perfect in every particular, all possible cutting and fitting to be done at the factory before delivery.

Protection of Terra Cotta.—All projecting terra cotta shall be protected with sound plank during erection of the building by terra cotta contractor, said protection pieces to be removed on cleaning down the building.

* From specifications of Fort Dearborn Building.

Cleaning Down.—This contractor shall carefully clean down all terra cotta work on completion of building, when directed by the superintendent, and shall carefully point up all joints before leaving the work.

SPECIFICATIONS FOR LATHING AND PLASTERING.

(ORDINARY WORK.)

385.—Lathing.—Lath all (walls) partitions, ceilings, and all furring, studding, under side of stairs, etc., with best quality of pine (spruce) lath, free from sap, bark or dead knots, and of full thickness. To be laid $\frac{3}{8}$ inch apart on the ceilings and $\frac{1}{4}$ inch or more on the walls, with four (five) nailings to the lath and joints broken every 18 inches; all to be put on horizontally. Under no circumstances must laths stop and form a long, straight vertical joint, nor any lath be put on vertically to finish out to angles or corners; neither shall any lath run through angles and behind studding from one room to another. All corners must be made solid before lathing. Should the lathers find any angles not made solid, or any furring or studding not properly secured, they are to stop and notify the carpenter to make permanent the same.

Metal Lathing.—Lath walls or partitions in front of hot-air pipes with metal lathing approved by the architect. Cover all recesses in brick walls that are to be plastered, all wood lintels and wherever woodwork joins the brick walls (if latter are not furred) with (Bostwick) or expanded metal lathing properly put up and secured.

Plastering—*Back-Plastering* (for frame buildings).—Back-plaster the whole of the exterior walls from sill to plate between the studs, also between the rafters of finished portion of attic, on laths nailed horizontally, $\frac{3}{8}$ inch apart, to other laths or vertical strips put on the inside of the boarding, with one heavy coat of lime and hair mortar, well troweled and made tight against the studs, girts, plates and rafters.

One-Coat Work.—Plaster the (basement ceiling) one heavy coat of rich lime and hair mortar, well troweled and smoothed.

Three-Coat Work.—All other walls, partitions, ceilings and soffits throughout the building to be plastered three coats in the best manner.

The first or scratch coat to be made of first quality (Rockland) lump lime, clean, sharp bank (river) sand, free from loam and salt, and best quality clean, long cattle hair, mixed in the proportion of $5\frac{1}{2}$ barrels of sand and $1\frac{1}{2}$ bushels of hair to each cask or each 200 pounds of lump lime. To be thoroughly mixed by continued working and stacked in the rough for at least (7) days before putting on. The hair and sand are not to be mixed with the lime until the lime has been slaked at least six hours.

The scratch coat to be properly put on and applied with sufficient force to give a good clinch, and to be well scratched and allowed to dry before the brown coat is put on.

The second or brown coat to be mixed same as the scratch coat (except that $6\frac{1}{2}$ barrels of sand and but $\frac{1}{2}$ bushel of hair to 1 of lime may be used). Level and float up the brown coat and make it true at all points.

White Coat.—The third coat (except in the halls and dining room) to be mixed with lime putty, plaster of Paris and marble dust (or lime putty and King's Superfine Windsor Cement), thoroughly troweled and brushed to a hard, smooth surface.

Sand Finish.—The third coat in halls and dining room to be composed of lime putty and clean-washed (beach) sand, floated with a wooden or cork-faced float to an even surface, equal to No. 1 sandpaper.

All lathing and plastering to extend clear down to the floor ; all walls to be straight and plumb and even with grounds ; all angles to be maintained sharp and regular in form.

Plaster Cornices, etc.—Run all around the (parlor) a plaster stucco cornice, to extend (8) inches on the ceiling and (6) inches on the wall, and to be run in strict accordance with detail drawing. Run all beads, quirks, etc., to angles of beam soffits as indicated on drawings, and finish at each end of beams with cast plaster brackets, modeled according to the architect's full-size detail.

Put up cast plaster centrepieces in (3) rooms, for which allow the sum of ($25) the same to be expended under the direction of the architect.

The plasterer must clear out all boards, planks, horses, mortar, dirt and all loose rubbish made by him or his men, and remove from the rooms and premises, as fast as the several stories are plastered, and leave the floors broom clean. *Patch up* and repair the plastering after the carpenters and other mechanics in a skillful manner and leave the work perfect on completion.

Two-Coat Work.—The following is the usual form of specification for house work in New England :

All walls, ceilings, soffits and partitions throughout the (first and second stories and attic) to be plastered two coats in the very best manner.

"The first coat to be of best quality (Rockland) lime and clean, sharp sand, well mixed with $1\frac{1}{2}$ bushels of best long cattle hair to each cask of lime; to be thoroughly worked and stacked at least one week before using in some sheltered place, but not in the cellar of the house ; all to be well troweled, straightened with a straight-edge and made perfectly true and brought well up to the grounds.

"The second or 'skim' coat to be of best (Rockland) lime putty and washed (beach) sand, troweled to a hard, smooth surface."

SPECIFICATIONS FOR HARD PLASTERING.

386.—All walls, ceilings, soffits and partitions throughout the building to be plastered three coats, in the best manner, as specified below.

The first and second coats to be of (Acme) cement plaster or dry mortar—the first coat on lath work to be fibred material.

The material to be mixed with clean water to the proper consistency and applied in the usual way. The first coat to be scratched or broomed to form a rough surface for brown coat. Apply the brown coat as soon as the scratch coat is two-thirds dry or has set sufficiently to receive it, bringing the mortar out even with the grounds and to a true surface. Scratch roughly for all stucco cornices and mouldings.

Sand Finish.—After the brown coat has been on twenty-four hours finish the walls and ceiling of (hall and vestibules) with (Windsor) sand finish, mixed with clean water only and floated to a true surface with clear soft pine or cork-faced floats.

[Or lime putty and sand may be used as in ordinary plastering.]

Hard Finish.—When the browning is two-thirds dry, finish all other walls and ceilings throughout the building with a white coat made of equal parts of lime putty and plaster of Paris, troweled and brushed to a hard and uniform surface.

[For a better grade of finish add a quart of marble dust to each batch of plaster, or use Windsor cement instead of plaster of Paris.]

All brick and tile walls and all wood laths to be well wet just before plastering.

Only as much mortar as can be used within one hour is to be mixed at one time, and under no circumstances shall any mortar that has commenced to set be retempered.

The plasterer must strictly observe and follow the directions accompanying the plaster.

[Specify for patching, cornices, etc., as in Section 385.]

SPECIFICATIONS FOR WIRE LATHING WITH METAL FURRING.

(OVER WOODWORK.)

This contractor is to fur all ceilings, soffits of stairs, all timber beams and posts, and both sides of all wood partitions throughout the building with Hammond's metal furring with (1)-inch bearings, the stiffening rods to be placed (6) (see Section 333) inches on centres, across floor beams and studding, and a line of furring to be placed on each side of each angle, as near the angle as possible. Posts and girders to be furred lengthways, with a line on each angle, and every 7½ inches between.

[If the architect does not wish to specify this furring he can specify $\frac{3}{32}$x$\frac{7}{8}$-inch corrugated band iron, put up with 1¾-inch staples.]

All furring to be substantially secured with 2-inch No. 13 steel staples (see Section 333) and to be set to give a true and even surface for the lathing.

Cover all the above surfaces with (plain, painted, japanned, galvanized) wire lathing (2½) (2½x5) mesh, No. (20) wire, tightly stretched and secured with (2)-inch No. 13 steel staples (see Section 333) driven over the lath and furring at each bearing where the lathing runs crossways of the timbers, and every (6) inches where the bearings run parallel with the timbers. The lathing to be lapped at least ½ inch where the strips come together and 1½ or 2 inches at all angles of walls or wall and ceiling.

SPECIFICATIONS FOR STIFFENED WIRE LATHING.

(OVER WOOD AND BRICKWORK.)

Cover all ceilings, soffits of stairs, both sides of all wood partitions, and all wooden posts and girders throughout the building with the (Roebling) stiffened wire lath, painted, No. 20 gauge, and (2½x5) (2½x2½) mesh, with ⅝-inch V-ribs. (For the posts and girders and on planking ¾-inch ribs will give better protection both from fire and dry rot.)

The lathing to be applied with the ribs running at right angles to the beams; to be tightly stretched and secured with galvanized steel nails, driven through each end of each rib, and at every bearing between and every 9 inches on timbers and planking. The strips to lap on a joist in every case and to be carried down 2 inches on the walls. Care must be exercised to see that no holes are left at any place in the ceiling where the plastering can drop off and fire enter.

Lath the outside walls of finished portion of basement, from floor to ceiling, with (Roebling) stiffened lathing, painted, No. 20 gauge, (2½x5) mesh and 1¼-inch V-ribs. To be tightly stretched, lapped 1 inch and secured to the walls with 10d. steel nails driven through the ribs every 8½ inches and at each end. The lathing to be applied with the stiffening bars vertical. All the above lathing to be done in the most approved manner so as to give a firm surface upon which to apply the plaster.

SPECIFICATIONS FOR METAL LATH ON IRONWORK.

This contractor is to furnish and put up in a substantial manner all iron furring and lathing for enclosing the posts and girders and for forming the cornices, as shown on the drawings and as specified below. The lathing to be well lapped on to walls and ceilings to make a tight job.

Girders.—All girders projecting below the level of ceilings shall be encased by wire lathing, stiffened with a $\frac{1}{4}$-inch solid rib. The lathing to be rigidly supported by light iron furring built out to correct outline as shown on the plans. The furring to be so designed that the weight of the plaster and falsework will be supported by the girder and so as to afford a firm surface for plastering.

Cornices.—Full-size details of all cornice work will be supplied by the architects at the proper time. Iron brackets, bent to correct outline and spaced not more than 18 inches apart, shall be secured in position in the best manner and well braced. Over this falsework wire lathing, stiffened with a $\frac{1}{4}$-inch steel rib, shall be laced so as to conform with the profile of the brackets and produce a smooth, firm surface for plastering.

Columns.—All columns not enclosed in brickwork are to be wire lathed. Suitable light iron furring shall be provided so as to offset the lathing at least 2 inches from the ironwork and finish round or square as shown on the plans. The lathing to be stiffened with a $\frac{1}{4}$-inch solid rib woven in every $7\frac{1}{2}$ inches.

All other exposed ironwork shall be suitably encased with wire lathing supported whenever necessary by light iron furring, and in all cases providing an air space of at least 1 inch between the ironwork and the plaster.

All the above lathing to be painted (galvanized), of No. 20 gauge and ($2\frac{1}{2}$x5) mesh, and to be securely laced to the furring with No. 19 galvanized lacing wire.

(All work here contemplated must comply with the requirements of the Department of Building.)

SOLID PARTITIONS.

(METAL LATH AND STUDDING.)

This contractor is to provide all metal work, and erect the partitions indicated by (gray) color or otherwise marked on the plans, and leave them in perfect condition for the plasterer. Wood furring will be furnished in pieces of the proper size by the carpenter, but this contractor is to secure them to the metal work. The above partitions to be formed of studs of $\frac{3}{8}$x$\frac{3}{4}$-inch channel iron, placed 16 inches centre to centre for partitions (11) feet high or less and 12 inches centre to centre for partitions more than (11) feet in height. All openings to be framed with 1x1-inch by $\frac{3}{16}$-inch angle irons.

Studs must be securely fastened at top and bottom, and grounds for door and window openings must be firmly secured to the studs. Grounds for nailing of base, chair rail, picture moulds, etc., must be fitted and fastened in true and straight, $\frac{1}{2}$ inch over the line of studs on face side of partition and $\frac{1}{4}$ inch over line of studs on reverse side, $1\frac{1}{2}$ inches total thickness.

2. After grounds are put on the face side of partition to be covered with (Bostwick steel lath put on with the loops inward or between the studs); the sheets of lath must come close together or lap on horizontal joints and the vertical joints must be broken properly ; the lath must be secured by nailing on with trunk nails, driven

through alongside of stud and clinched around behind it, each nail being on opposite side of stud from the one above and below it. The metal work must be properly braced to hold it in position until the mortar has become firm.

(The bracing should be a straight-edged flooring board put on over the lath, and staples set around the studs driven into the board can be easily drawn afterward, leaving only 1 inch of strip to fill in on face of partition and the staple holes on reverse after partitions become rigid.)

[For wire lathing specify as follows instead of as in paragraph 2.]

3. After grounds are put on cover one side of the partition with No. 20 painted ($2\frac{1}{2}$x5) mesh wire lathing, stiffened with a $\frac{1}{4}$-inch solid steel rib woven in at intervals of $7\frac{1}{2}$ inches, the rods to run crossways of the studs. The lathing to be firmly secured to the studding by No. 19 galvanized lacing wire.

SPECIFICATIONS FOR THE "ROEBLING FIREPROOF FLOOR."

[This specification is given as a guide in preparing specifications for this and similar floors. Most of the various fireproofing companies have printed specifications for their systems, which they furnish to architects on application.]

The floor construction to be used in this building shall be that known as the "Roebling System," consisting of a steel-ribbed wire cloth and concrete arch with ceilings suspended below the level of the floor beams. A continuous air space between the floor and ceiling and around the girders shall be provided.

The wire centring for the floors shall consist of No. 19, four-warp two-filling wire cloth stiffened with $\frac{3}{8}$ to $\frac{1}{2}$-inch steel rods woven into the cloth at intervals of about 9 inches. This centring shall be sprung in between the I-beams in the form of an arch with the ends of the rods abutting against the beams. The sheets to be well lapped and securely laced. Over the crown of this centring one or more $\frac{5}{16}$-inch steel rods shall be laced parallel to the beams to secure proper longitudinal bracing.

In all spans over 3 feet 6 inches a heavy galvanized wire shall be dropped down from the stiffening rib of the arch at intervals of not over 3 feet to support the ceiling.

Over the wire arch so constructed cinder concrete mixed in the proportions of 1 part of high-grade Portland cement to 2 parts of sharp sand and 5 parts of clean cinder shall be laid to a sufficient thickness to secure the required strength, as designated elsewhere in these specifications. The concrete generally to be leveled (2 inches above) the top of the floor beams where wood floors are specified, and to the specified levels where other than wood floors are designated.

Every alternate nailing-sleeper to be imbedded in concrete so as to form a fire stop. These sleepers to be supplied and placed in position over the beams under the carpenter's contract.

The floors to be subject to test at any point that may be designated by the architect, and at any time after the concrete is fifteen days old. The floor shall in all cases develop a strength of 1,000 pounds per square foot when the load is concentrated, and similarly a strength of 600 pounds per square foot when the load is uniformly distributed *over one-half of the span.*

APPENDIX.

The following tables relating to the properties and chemical composition of building stones, and to stone buildings, have been compiled by the author from various sources (principally from several volumes of *Stone* and Merrill's *Stones for Building and Decoration*), and are believed to be reliable :

TABLE A.

Showing the Weight, Crushing Strength and Ratio of Absorption of Various Building Stones.

Kind of Stone.	Locality.	Approximate size of cube in inches.	Position.	Strength per square inch.	Weight per cubic foot.	Ratio of Absorption.
Granite (Biotite)........	Vinalhaven, Me........	2	Bed	15,698	163	....
"	Dix Island, Me........	2	....	15,000*	166.5	....
"	Hurricane Island, Me...	2	Bed	14,425*	166.9	....
"	" " ...	2	Edge	14,937*	166.9	....
"	Fox Island, Me........	2	....	14,875*	164.1	....
"	Keene, N. H..........	2	Bed	10,375	166	$\frac{1}{300}$
Granite (Hornblende)...	Cape Ann, Mass........	2	Bed	12,423*	......	....
" ...	" "	2	Bed	19,500*	......	....
...	Rockport, Mass........	2	Bed Edge	16,300 19,750	163.2	$\frac{1}{152}$
" ...	Quincy, Mass..........	2	....	17,750†	166.2	....
" ...	"	2	....	14,750†	168.7	....
Granite (Biotite)........	Milford, Conn.........	6	....	22,610	......	....
"	Westerly, R. I.........	2	....	17,500	165.6	....
"	"	2	Edge	14,937*	166.9	....
"	Huron Island, Mich....	2	Bed	18,125	164.4	$\frac{1}{659}$
"	" "	2	Edge	14,425	163.7	$\frac{1}{363}$
Granite (Hornblende)...	East Saint Cloud, Minn.	2	Bed Edge	28,000 26,250	168.2	....
" ...	Saint Cloud, Minn......	2	Bed Edge	16,000 18,500	168.2	$\frac{1}{239}$
Granite (Gabbro).......	Duluth, Minn..........	2	Bed	17,631	175	....
Granite (Biotite)........	Tarrytown, N. Y.......	2	Bed	18,250†	162.2	....
"	Staten Island, N. Y....	2	Bed	22,250†	178.8	....
"	Gunnison, Colo........	2	Bed Edge	12,976 15,594	.006	....
"	Platte Canon, Colo.....	2	Bed Edge	14,585 14,634	.006	....
Limestone (Dolomite)...	Joliet, Ill..............	2	Bed	14,775*	160	$\frac{1}{94}$
" ...	Lemont, Ill...........	2	Bed	12,000*	165.3	$\frac{1}{89}$
" ...	Quincy, Ill............	2	Bed	9,687*	160.6	$\frac{1}{180}$
Limestone (Oolitic).....	Bedford, Ind..........	..	....	6,500	147	$\frac{1}{24}$
"	"	..	....	10,125	152.4	$\frac{1}{32}$
"	" (buff)	..	....	14,000‡	......	....
"	Salem, Ind............	..	....	8,625	144.3	$\frac{1}{22}$
Limestone (Dolomite)...	Stillwater, Minn........	2	Bed Edge	25,000 25,000	172.6	$\frac{1}{251}$
" ...	"	2	Bed Edge	10,750 12,750	160.4	$\frac{1}{40}$

* Burst suddenly. † Cracked before bursting ‡ Tests made at U. S. Arsenal, Watertown, Mass.

TABLE A.—(Continued.)

Kind of Stone.	Locality.	Approximate size of cube in inches.	Position.	Strength per square inch.	Weight per cubic foot.	Ratio of Absorption.
Limestone (Dolomite)...	Red Wing, Minn.......	2	Bed Edge	23,000 23,250	162.2	1/40
Limestone (Magnesian)..	Glens Falls, N. Y......	2	Bed Edge	11,475* 10,750	168.8	....
" ..	Lake Champlain, N. Y.	2	Bed Edge	25,000* 21,500	171.9	....
Marble (Dolomite).....	Lee, Mass............	6	Bed	22,900	......	....
"	Centre Rutland, Vt.....	6 ‡	....	10,746	166.6	....
"	Dorset, Vt............	2	Edge	8,670	167.8	....
"	"Cherokee," Georgia...	6	....	10,976	......	....
"	" ...	4 ‡	....	13,415	......	....
"	" ...	4 ‡	....	11,822	......	....
"	"Creole," Georgia.....	6	....	12,078	......	....
"	"	4 ‡	....	11,420	......	....
"	"	4 ‡	....	15,512	......	....
"	"Etowah," Georgia....	6	....	10,642	......	....
"	"	4 ‡	....	14,217	......	....
"	"	4 ‡	....	13,888	......	....
"	"Kennesaw," Georgia..	4 ‡	....	8,354	......	....
"	" ..	4 ‡	....	10,771	......	....
Marble (Pink)..........	East Tennessee.........	2	....	15,750	......	1/1220
Marble (White)........	"	2	....	17,212	......	1/1240
"	"	2	....	14,812	......	1/1480
Marble (Dark Pink).....	"	1	....	13,750	......	1/1070
Sandstone (Brownstone).	Portland, Conn.........	2½‡	....	13,980	......	....
" ..	"	2½‡	....	13,330	......	....
" ..	"	3 ‡	....	13,920	......	....
" ..	"	3 ‡	....	15,020	......	....
" ..	"	2½‡	....	9,900	......	....
" ..	Cromwell, Conn........	2½‡	Bed	12,250	Average of 6 tests	
Sandstone (Con.)						
" Brown (soft)..	East Longmeadow, Mass	4 ‡	....	8,437	......	....
" " (hard).	" "	4 ‡	....	14,085	......	....
" (Kibbe)......	" "	6 ‡	....	12,619	......	....
" "	Potsdam, N. Y.........	2 ‡	....	18,401	......	....
" "	"	2 ‡	....	42,000	......	....
" (lilac color)...	Medina, N. Y.........	2	Bed	17,250	150.6	1/55
" (light).......	North Amherst, Ohio...	2	Edge	5,450	133.7	1/19
" "	" " ...	2	Bed	6,212	135.8	1/19
" "	Berea, Ohio............	6	Bed	6,510	......	....
" "	"	2	Bed	8,222	134	1/21
" "	Cleveland, Ohio........	2	Bed	6,800	140	1/37
" "	Hummelstown, Pa......	6	Bed	12,810	......	....
" "	Fond du Lac, Wis......	2	Bed	6,237	138.8	1/22
" (hard, red)...	Saint Vrains, Colo......	2	Bed	11,505	149.3*	.061
" (hard, gray)..	Fort Collins, Colo......	2	Bed	11,707	140.7	.072
" " ..	Stout, Colo...........	2	Bed	10,514	141.2	.066
" (light red)....	Manitou, Colo.........	2 ‡	Bed	11,000	140	....
" "	"	2	Bed	6,000	......	....

* Burst suddenly. † Cracked before bursting.
‡ Tests made at U S. Arsenal, Watertown, Mass.

TABLE A.—(Continued.)

SLATE.

Locality.	Modulus of Rupture.	Weight per cubic foot.	Porosity.	Corrodibility.
Albion, Penn.................	7,150 lbs.	173.2	0.238	0.547
Old Bangor, Penn.............	9,810 "	173.5	0.145	0.446
Peach bottom region, Penn.....	11,260 "	180.4	0.224	0.226

TABLE B.

SHOWING THE CHEMICAL COMPOSITION OF VARIOUS BUILDING STONES.*

GRANITES.

Description.	Locality.	Silica.	Alumina.	Iron Oxides.	Lime.	Potash and Soda.
Light.............	Monson, Mass..........	73.47	15.07	1.15	4.48	5.97
Dark	"	69.35	18.83	2.00	5.94	3.78
Hornblende........	East Saint Cloud, Minn.	65.12	16.96	4.69	4.77	5.25
"	" " ..	74.43	12.68	3.82	1.28	3.88
Diabose...........	Duluth, Minn..........	50.43	23.83	17.63	4.79	2.40
Gabbro............	"	48.51	13.79	19.34	8.34	1.86

SANDSTONES.

Description.	Locality.	Silica.	Alumina.	Iron Oxides.	Lime.	Water and Loss.
Maynard (red)......	E. Longmeadow, Mass. .	79.38	8.75	2.43	2.57	2.79
Worcester (red).....	" " ..	88.89	5.95	1.79	.27	1.83
Kibbe quartz......	" " ..	81.38	9.44	3.54	.76	4.49
Brownstone	Portland, Conn.........	69.94	13.15	2.48	3.09	1.01
"	"	70.11	13.49	4.85	2.39	7.37†
Sandstone..........	Stony Point, Mich......	84.57	5.90	6.48	....	1.92
Portage Entry (red).	Lake Superior, Mich....	94.73	0.36	2.64	0.69	.83
Quartzite..........	Pipestone, Minn........	84.52	12.33	2.12	0.31	2.31
Buff	Amherst, Ohio.........	97.00	.....	1.00	1.15	.21
Berea.............	Berea, Ohio...........	96.90	.....	1.68	.55	.32
Euclid Bluestone...	Euclid County, Ohio....	95.00	2.50	1.00	....	1.50
Columbia..........	Columbia, Ohio........	96.50	.....	....	....	2.00
Red	Laurel Run, Pa........	94.00	.....	1.90	1.10	1.92
Elyria	Grafton, Ohio..........	87.66	1.72	3.52	.17	2.03
Sandstone..........	Fond du Lac, Minn....	78.24	10.88	3.83	.95	....
"	Flagstaff, Arizona......	79.19	3.75		7.76	3.26
"	Dorchester, N. Brunsw'k	82.52	7.07	3.55	1.83	3.61

* Some minor elements occurring in very small quantities and not affecting the durability of the stone are omitted.

† Potash and soda.

TABLE B.—(Continued.)

LIMESTONES OTHER THAN MARBLES.

Description.	Locality.	Carbonate of Lime.	Carbonate of Magnesia.	Oxides of Iron.	Oxide of Aluminum.	Silica and insoluble residue.	Water and Loss.
Dolomite............	Lemont, Ill............	45.80	......	2.30	7.00	15.90	6.90
Oolitic................	Bedford, Ind..........	96.60	0.13	0.98		0.50	0.96
"	"	97.26	0.37	0.49	....	1.69	0.19
" (buff)..........	"	98.20	0.39	0.39	....	0.63	.....
" (blue)..........	"	97.26	0.37	0.49	....	1.69	.....
"	Spencer, Ind..........	96.80	0.11	0.91	....	0.70	0.92
Oolitic................	Bowling Green, Ky.....	95.31	1.12	0.39	....	1.42	1.76
Dolomite..............	Minneapolis, Minn.....	54.53	36	0.90	3.16	16.22	0.375
"	"	41.88	24.55	4.03	....	29.93	.....
"	"	75.48	6.81	1.70	....	14.45	1.60
"	Kasota, Minn..........	49.16	37.53	1.09	....	13.06	.....
"	Stillwater, Minn........	50.22	37.39	0.78	0.64	8.54	.....
"	Frontenac, Minn.......	54.78	42.53	0.36	0.31	2.93	.....
Limestone.............	Dayton, Ohio..........	92.40	1.10	0.58	....	1.70	1.08
Dolomite..............	Springfield, Ohio.......	54.70	44.93	0.20	....	0.10	.....
Limestone (Caen).......	Aubigney, France......	97.60	......	....	....	1.70	.....
" (Oolitic).....	Portland, England......	95.16	1.20	0.50	....	1.20	1.94

MARBLES.

Description.	Locality.	Carbonate of Lime.	Carbonate of Magnesia.	Oxides of Iron and Aluminum.	Insoluble Residue.
Dolomite................	Hastings, N. Y......	52.82	45.78	....	....
" (white)..........	Sing Sing, N. Y......	53.24	45.89	....	....
"	Tuckahoe, N. Y......	61.75	38.25	....	....
" (white)..........	Pleasantville, N. Y...	54.62	45.04	0.23	....
" "	Lee, Mass...........	54.62	43.93	.365	....
Limestone (white).......	Rutland, Vt..........	97.73	.....	.59	1.68
" (greenish)......	"	85.45	.....	14.55	....
" (white)........	West Rutland, Vt....	98.00	.....	....	0.57
" (bluish gray)...	Proctor, Vt..........	98.37	0.79	0.005	0.63
" (light colored)..	"	96.30	3.06	....	0.63
"	East Tennessee......	98.78	0.67	0.26	.08
Georgia Marble Co.......	Georgia.............	97.32	1.60	.26	....
Southern Marble Co.....	"	98.96	0.13	.22	....
" "	"	98.52	0.88	....	....
Carrara (white)..........	Italy................	99.24	0.28	....	....
"	"	98.76	0.9	1.08	0.16

TABLE B.—(Continued.)

ONYX MARBLES.

Source.	Color.	Weight per cubic foot.	Carbonate of Lime.	Carbonate of Magnesia.	Carbonate of Iron.
Hacienda del Carmen, Mexico.....	Light green..........	171.87	89.36	3.00	5.24
Mayer's Station, Arizona..........	"	171.87	93.93	0.56	5.50
" "	Red brown..........	166.87	93.82	0.53	4.06
Cave Creek, Arizona..............	Light green..........	171.87	93.48	1.07	5.19
Suisin City, California............	Dark amber..........	170.62	95.48	2.20	....
Sulphur Creek, "	"	167.5	.....	....	....
San Luis Obispo, California........	White...............	170	93.68	1.43	3.93
Rio Puerco, Valencia County, New Mexico......................	Light green..........	179.37	.....	....	....
New Pedrara, Lower California....	Faintly green........	174.37	90.16	1.66	6.97
" "	White, rose tinted....	173	93.48	1.68	4.19
" "	White...............	174	96.86	0.24	2.79
" "	Faintly green........	174.37	91.09	0.64	7.49
Near Lehi, Utah.................	Yellow.............	170	97.61	0.23	....

SLATES.

Source.	Silica.*	Alumina.*	Protoxide of Iron.*	Peroxide of Iron.*	Magnesia.	Alkalies.
Rutland County, Vt. (sea green)........	65.02	16.02	5.44	2.99	2.00	4.16
" (unfading green)...	64.71	7.84	5.44	7.23	1.63	6.92
" (purple)..........	62.37	13.40	4.21	7.66	0.90	7.20
Granville, N. Y. (red).................	73.97	5.16	1.74	10.17	1.43	3.92
Old Bangor, Penn. (dark).............	56.97		26.05		2.69	2.31
Albion, Penn. (dark)..................	55.18	.....	25.57	carbon	2.10	4.00
Peach Bottom Region, Penn. (dark).....	58.37	21.98	10.66	0.93	1.20	1.93

* These are the valuable constituents. "Peroxide of iron is probably the coloring matter."

TABLE C.

List of Important Stone Buildings in the United States.

[Given to enable architects to see the appearance and weathering qualities of the different stones.*]

GRANITE BUILDINGS.

Locality of Quarries.	Name of Building.	City.
Dix Island, Me	Post Office	New York City.
"	(New) Post Office	Philadelphia, Pa.
Hallowell, Me	State Capitol	Albany, N. Y.
"	State Capitol	Augusta, Me.
"	Equitable Insurance Co. Building	Boston, Mass.
Cape Ann, Mass	Post Office	"
Milford, Mass	City Hall	Albany, N. Y.
Quincy, Mass	U. S. Custom House	Boston, Mass.
"	Bunker Hill Monument	Charlestown, Mass.
"	Post Office	Providence, R. I.
"	Astor House	New York City.
"	Philadelphia National Bank	Philadelphia.
"	Presbyterian Church	Savannah, Ga.
"	U. S. Custom House	Mobile, Ala.
"	U. S. Custom House	New Orleans, La.
Concord, N. H	Congressional Library	Washington, D. C.
"	State Capitol	Concord, N. H.
Gunnison, Colo	State Capitol	Denver, Colo.
Little Cottonwood Canon, Utah	Mormon Assembly House and Temple	Salt Lake City, Utah.

LIMESTONE BUILDINGS.

Locality of Quarries.	Name of Building.	City.
Lockport, N. Y	Lenox Library	New York City.
Bedford, Ind	Algonquin Club Building	Boston, Mass.
"	Residence of Mr. Robert Goelet	Newport, R. I.
"	Manhattan Life Insurance Building	New York City.
"	Mail and Express Building	"
"	American Fine Arts Society Building	"
"	Residences of Cornelius Vanderbilt and W. K. Vanderbilt	" (Fifth Avenue).
"	Manufacturers' Club Building	Philadelphia, Pa.
"	Tioga Baptist Church	"
"	State Capitol	Indianapolis, Ind.
"	Auditorium Building	Chicago, Ill.
"	Union Station	St. Louis, Mo.
"	Cotton Exchange Building	New Orleans, La.
"	Biltmore	Biltmore, N. C.
Lemont, Ill	St. Paul Universalist Church	Chicago, Ill.
"	Central Music Hall	"
St. Paul, Minn	Catholic Cathedral	St. Paul, Minn.
Kaosta, Minn	Post Office	"
Bowling Green, Ky	U. S. Custom House	Nashville, Tenn.

* Some of these stones are used in a great many other buildings in the cities mentioned, the idea of the author being to give only one or two examples in each city.

TABLE C.—(Continued.)

MARBLE BUILDINGS.

Locality of Quarries.	Name of Building.	City.
Rutland, Vt.	(Old) Parker House, on School Street	Boston, Mass.
Lee, Mass.	St. Patrick's Cathedral (in part)	New York City.
"	New City Buildings	Philadelphia, Pa.
"	Washington Monument (in part)	Washington, D. C.
"	U. S. Capitol Extension	"
Tuckahoe, N. Y.	New York Life Insurance Building	Boston, Mass.
"	Hotel Vendome (new part)	"
Montgomery County, Pa.	Girard College	Philadelphia, Pa.
East Tennessee	Blackstone Memorial Library	Branford, Conn.
"	U. S. Custom House and Post Office	Knoxville, Tenn.
"	U. S. Custom House and Post Office	Memphis, Tenn.
"	U. S. Custom House and Post Office	Chattanooga, Tenn.
Georgia	Trimmings, Ames Building	Boston, Mass.
"	St. John's Episcopal Church	Knoxville, Tenn.
"	Grand Opera House	Atlanta, Ga.
"	U. S. Custom House and Post Office	Jacksonville, Fla.

SANDSTONE BUILDINGS.

Locality of Quarries.	Name of Building.	City.
Longmeadow, Mass. (red stone)	Trimmings, Trinity Church	Boston, Mass.
Longmeadow, Mass. (red stone)	Union League Club House	Chicago, Ill.
Portland, Conn. (brownstone)	Technology (original) Building	Boston, Mass.
" "	Alumni Hall, Library and Art School, Yale College	Hartford, Conn.
" "	Residences of Wm. H. Vanderbilt and Messrs. Twombly and Webb	New York City (Fifth Avenue).
" "	Astor Library	New York City.
" "	Academy of Design (Montague Street)	Brooklyn, N. Y.
" "	Music Hall	Buffalo, N. Y.
" "	Union League Club Building	Philadelphia, Pa.
" "	Residence of Geo. H. Pullman	Chicago, Ill.
" "	Savings Bank of Baltimore	Baltimore, Md.
Potsdam, N. Y. (red stone)	Parliament Buildings	Ottawa, Ont.
" "	Columbia College	New York City.
" "	All Saints Cathedral	Albany, N. Y.
Ohio Sandstone (buff stone)	Palmer House	Chicago, Ill.
" "	State Capitol	Lansing, Mich.
Portage Entry, Mich. (red stone)	State Mining School Buildings	Houghton, Mich.
Fond du Lac, Minn. (reddish brown stone)	Westminster Presbyterian Church	Minneapolis, Minn.
Kettle River, Minn.	Board of Trade Building	West Superior, Wis.
Fort Collins, Colo. (dark red stone)	Grace Methodist Church	Denver, Colo.
Fort Collins, Colo. (dark red stone)	Union Pacific Depot	Cheyenne, Wy.
Fort Collins, Colo. (dark red stone)	American Exchange Bank	Kansas City, Mo.
Manitou, Colo. (red stone).	Boston Building	Denver, Colo.

TABLE D.

THE EFFECT OF HEAT ON VARIOUS BUILDING STONES.*

Kind.	Locality.	Weight per cubic foot in pounds.	Ratio of absorption.	First appearance of injury. Degrees F.	First appearance of cracking or crumbling. Degrees F.	General cracking and friability. Degrees F.	Rendered worthless. Deg. F.	Melted or destroyed. Degrees F.
Light colored granite	Hallowell, Me	164.8	1-790	800	900	950	1,000	1,100
Red granite	Stark, N. H	164.1	1-534	600	700	800	850	950
Carter's Quarry granite	Woodbury, Vt	165.8	1-784	800	900	950	1,000	1,200
Syenite	Quincy, Mass	166.2	1-650	750	800	850	900	1,000
Common granite	Woodstock, Md	165.5	1-394	700	750	800	900	900
Old Dominion Quarry granite	Richmond, Va	167.7	1-402	750	800	850	900	1,000
Light colored granite	St. Cloud, Minn	168.2	1-280	700	700	800	850	900
Sandstone	Portland, Conn	148.7	1-27	850	900	950	1,000	1,100
Sandstone	Seneca, Md	150.6	1-40	900	1,000	1,100	1,200	1,200
Sandstone	Nova Scotia	151.5	1-240	900	950	1,000	1,000	1,100
Potsdam sandstone	McBride's Corners, O	145.8	1-28	800	850	900	1,000	1,100
Berea sandstone	Berea, O	140.8	1-20	850	900	950	1,000	1,000
Limestone	Baltimore, Md	181.8	2-340	900	1,000	1,100	1,200	1,200
Limestone	Bedford, Ind	154.8	1-280	850	900	1,000	1,200	1,200
Cincinnati limestone	Hamilton County, O	137.7	1-28	850	900	950	1,200	1,200
Potts' blue limestone	Springfield, Penn	166.6	1-280	850	850	900	1,000	1,200
Dolomite limestone	Owen Sound, P. O	160.6	1-480	850	900	1,100	1,200	1,200
Trenton limestone	Montreal, P. Q	169.1	1-316	900	950	1,000	1,200	1,200
Limestone	Isle La Motte, Vt	168.5	1-320	950	1,000	1,100	1,200	1,200
Tuckahoe marble	Westchester County, N. Y.	174.6	1-298	900	1,000	1,200	1,200	1,200
Ashley Falls marble	Ashley Falls, N. Y.	171.3	1-280	900	1,000	1,100	1,200	1,200
Snowflake marble	Westchester County, N.Y.	178.0	1-380	950	950	1,000	1,200	1,200
Tennessee marble	Dougherty's Quarry, East Tennessee.	169.4	1-320	950	950	1,000	1,200	1,200
Duke marble	Near Harper's Ferry, Va	175.7	1-340	1,000	1,000	1,100	1,200	1,200
Black marble	Isle La Motte, Vt	176.6	1-320	1,000	1,000	1,100	1,200	1,200
Sutherland Falls marble	Rutland, Vt	166.6	1-342	1,000	1,000	1,100	1,200	1,200
Conglomerate	Roxbury, Mass	169.2	1-49	700	800	900	1,000	1,000
Potomac stone	Point of Rocks, Md	170.2	1-60	600	700	800	900	900
Conglomerate	Caps a La Aisle, P. Q	165.3	1-80	600	700	800	900	900
Artificial stone	McMurtire and Chamberlain Patent	139.7	1-280	750	800	1,100	1,200	.....

* From "Notes on Building Stones," by Dr. Hiram Cutting, Montpelier, Vt., 1880.

"The experience of the citizens of North Arkansas is that marble is much superior to the sandstone in withstanding heat, and because of this fact, where chimneys are built of sandstone the fireplaces are lined with marble."

TABLE E.

TABULATED RESULTS OF THE ACTUAL CRUSHING STRENGTH OF BRICK PIERS MADE BY THE U. S. GOVERNMENT AT WATERTOWN, MASS.

BUILT OF FACE-BRICKS (M. W. SANDS, CAMBRIDGE, MASS.). AGE, 18 TO 24 MONTHS.

Nominal Dimensions. Height.		Cross-section.		Composition of mortar.	Weight per cubic foot.	Sectional area.	First crack.	Ultimate strength. Total.	Per sq. in.	Per sq. ft.	% of single brick.
Ft.	In.	In.	In.		lbs.		lbs.	lbs.	lbs.	Tons.	
1	4	8	8	1 lime, 3 sand,	137.4	57.00	85,000	143,600	2,520	181.4	18.1
6	8	8	8	" "	133.5	57.76	50,000	108,400	1,877	135.1	13.5
1	4	8	8	1 Portland cement, 2 sand,	136.3	57.76	200,000	218,100	3,776	271.8	27.1
6	8	8	8	" "	133.5	57.76	85,000	129,900	2,249	161.9	16.2
2	0	12	12	1 lime, 3 sand,		132.25	140,000	257,100	1,940	139.7	13.9
a 2	0	12	12	" "		113.76	90,000	226,100	1,990	143.3	14.3
10	0	12	12	" "	131.7	132.25	70,000	199,800	1,511	108.8	10.9
b 10	0	12	12	" "	125.0	115.44	100,000	208,600	1,807	130.1	13.0
2	0	12	12	1 Portland cement, 2 sand,		132.25	200,000	486,000	3,670	264.2	26.4
10	0	12	12	" "	132.2	132.25	200,000	298,000	2,253	162.2	16.2
BUILT OF COMMON BRICKS (M. W. SANDS).											
1	4	8	8	1 lime, 3 sand,	135.6	60.80	66,000	148,800	2,440	175.6	13.3
6	8	8	8	" "	133.6	62.40		96,100	1,540	110.8	8.4
2	0	12	12	" "		138.06	75,000	296,400	2,150	154.8	11.7
9	9	12	12	" "	131.5	138.06	70,000	154,300	1,118	80.5	6.1
c 10	0	12	12	" "	136.0	115.50	70,000	183,300	1,587	114.3	8.6
10	0	12	12	1 Portland cement, 2 sand,	131.0	138.06		276,600	2,003	144.2	10.9
2	8	16	16	" " "		256.00	460,000	696,000	2,720	195.8	14.8
10	0	16	16	" " "		256.00	340,000	483,100	1,887	135.8	10.3

a Has hollow core 4.25x4.25 inches. *b* Has hollow core 4.1x4.1 inches. *c* Has hollow core 4.75x4.75 inches.

BUILT OF COMMON BRICKS (BAY STATE).

Height. Ft.	In.	Cross-section. In.	In.	Composition of mortar.	Weight per cubic foot.	Sectional area.	First crack.	Total.	Per sq. in.	Per sq. ft.	% of single brick.
d 6	0	12	12	1 lime, 3 sand,	118.2	144.00	80,000	191,600	1,331	95.8	11.7
e 6	0	12	12	" "	118.1	156.25	110,000	189,200	1,211	87.2	10.6
6	0	12	12	1 Rosendale cement, 2 lime mortar,	120.6	144.00	160,000	237,000	1,646	118.5	14.4
6	0	12	12	" " 2 sand,	123.0	144.00	260,000	284,000	1,972	142.0	17.3
6	0	12	12	1 Portland cement, 2 lime mortar,	120.3	144.00	150,000	203,200	1,411	101.6	12.4
6	0	12	12	" " 2 sand,	119.7	144.00	220,000	258,000	1,792	129.0	15.7
6	0	12	12	Neat Portland cement,	126.6	144.00	280,000	342,000	2,375	171.0	20.8

d Joints broken every 6 courses. *e* Bricks laid on edge.

TABLE F.

Safe Working Loads for Masonry.

(From the *Architects' and Builders' Pocket Book.*)

BRICKWORK IN WALLS OR PIERS.

Tons per square foot.	Eastern	Western
Red brick in lime mortar	7	5
" hydraulic lime mortar		6
" natural cement mortar, 1 to 3	10	8
Arch or pressed brick in lime mortar	8	6
" " " natural cement	12	9
" " " Portland cement	15	12½

Piers exceeding in height six times their least dimensions should be increased 4 inches in size for each addititional 6 feet.

STONEWORK.

(Tons per square foot.)	
Rubble walls, irregular stones	3
" coursed soft stone	2½
" " hard stone	5 to 16
Dimension stone, squared in cement:	
Sandstone and limestone	10 to 20
Granite	20 to 40
Dressed stone, with ⅜-inch dressed joints in cement:	
Granite	60
Marble or limestone, best	40
Sandstone	30

Height of columns not to exceed eight times least diameter.

CONCRETE.

Portland cement, 1 to 8	8 to 20*
Rosendale cement, 1 to 6	5 to 10
Hydraulic lime, best, 1 to 6	5

HOLLOW TILE.

(Safe loads per square inch of effective bearing parts.)	
Hard fire-clay tiles	80 lbs.
" ordinary clay tiles	60 "
Porous terra cotta tiles	40 "

MORTARS.

(In ⅛-inch joints, 3 months old, tons per square foot.)	
Portland cement, 1 to 4	40
Rosendale cement, 1 to 3	13
Lime mortar, best	8 to 10
Best Portland cement, 1 to 2, in ¼-inch joints for bedding iron plates	70

* "The concrete and twisted iron columns in the Pacific Coast Borax Works, 16 inches in diameter and 1: feet high, are habitually loaded with about :6 tons to the square foot."—*E. L. Ransome.*

TABLE G.

PROPERTIES OF TIMBER, STONES, IRON AND STEEL.

(Values for strength are those given in the *Architects' and Builders' Pocket Book.*)

	Weight per cubic foot in pounds. Average.	Weight per foot, B. M. in pounds. Average.	Safe Tensile Strength, per square inch.	Safe Crushing Strength in pounds per square inch.	Safe Centre Load for Beam 1 inch square and 1 foot long.*	Safe Shearing Strength with the Grain, pounds per square inch.	Safe Crushing Strength across the Grain, pounds per square inch.
Chestnut	40	3.3	1,500	530	60	....	....
Hemlock	30	2.5	1,200	450	55	70	200
Oak, white	52	4.3	2,000	750	75	150	600
Pine, Georgia yellow	43	3.6	2,000	1,000	100	120	500
Pine, Oregon	36	3	1,800	750	90 †	100	400
Pine, Norway	36	3	1,600	700	70	90	400
Pine, white Western	30	2.5	1,500	625	65	80	200
Redwood	..	..	800	600	60	70	175
Spruce	36	3	1,800	625	70	90	250
Whitewood	35	3	1,200	500	65	....	200
Slate	174	..	....	....	40	....	....
Bluestone flagging	...	..	....	....	25	....	....
Granite	167	..	....	850	18	....	....
Limestone (Ind.)	158	..	....	550	18	....	....
Marble	170	..	....	550	18	....	....
Sandstone	139	..	....	450	12	....	....
Cast iron	450	..	2,600	13,500	308	7,000	....
Wrought iron	480	..	10,000	10,000	666	7,500	12,000
Steel, medium	490	..	12,500	13,000	888	7,500	12,000
" pins	...	..	....	....	..	7,500	12,000
" rivets	...	..	....	....	..	7,500	15,000

* One-eighteenth of the "fibre strain" or safe "Modulus of Rupture"

† **For full permanent loads, such as brick walls, etc., use only four-fifths of these values.**

MAKING CELLARS WATERPROOF.

Quite often in cities it is desirable to construct a dry basement in localities where water permeates the soil to within a few feet of the sidewalk.

In such cases it is necessary not only to make the walls and floor waterproof, but also to give sufficient thickness to the floor that the buoyant force of the water will not cause it to break through.

To make the cellar water-tight the entire area of the cellar should be covered with concrete, after the footings of the walls and piers are in, from 3 to 6 inches thick, so that the concrete will be level with the top of the footings. A narrow course of brick or stone should then be laid along the centre of the footings, as shown in Fig. 249, to form a break. Upon the top of the footings three thicknesses of tarred felt or burlap should then be mopped in hot asphalt, the felt being allowed to project 6 inches on

each side. A similar layer of felt and asphalt should be laid over the footings of all piers, engine foundations, etc., and allowed to project at least 6 inches on all sides.

After the external walls are completed, and before "filling in," the projecting felting should be turned up and mopped with hot asphalt against the wall, and the entire outside surface of the wall to the sidewalk line covered with three thicknesses of felt laid breaking joints in hot asphalt and overlapping the felt that comes through the wall. For further protection this covering is also frequently plastered with 1 to 2 Portland cement mortar.

Before the completion of the building the entire cellar floor must also be covered with felt in hot asphalt, laid in at least three thicknesses, breaking joint and overlapping the felt first laid. On the top of the felt thus laid there should then be laid Portland cement concrete at least 1 inch thick for each 3 inches in depth of the water above the level of the cellar bottom, with a minimum depth of 6 inches.

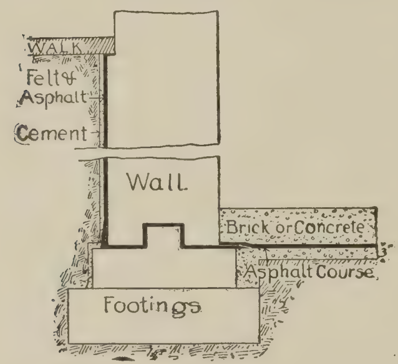


Fig. 249.

The following description of the waterproofing of the basement of the *Herald* Building, in New York City, is given as an actual example of the above method:*

In this building the printing presses are placed in the basement, and great pains were taken to exclude moisture below grade. The footings and outside basement walls were covered with four-ply burlap mopped on solid, commencing at the inner edge of sidewalk and back over top of vault and down the outside of the wall to the bottom of the same, thence through the wall and turned up against same for connection to the waterproof course.

Beneath the surface of the entire basement, including floor of vaults, the best four-ply roofing felt was mopped on solid, and similar material was used in connection with all piers, extending in each case through the entire thickness of the pier and beneath the entire surface of foundations for boilers and machinery.

The felt was securely lapped and turned up around all walls. Above the felt 4 inches of concrete was laid in the basement and 16 inches in the boiler room.

If less expensive, hard bricks laid in cement mortar and at least three courses in thickness, may be used instead of the concrete above the felt.

* From the *Engineering Record*, July 1, 1893.

STAIN AND DAMP-PROOFING.—ANTIHYDRINE.

In Section 301 attention has been called to the frequent staining of plastering applied on fireproof tiling, which has proved a source of much trouble in getting a fine decorative surface, the stains showing even through oil paint.

Similar trouble is also sometimes experienced with plastering applied directly to the brickwork of outside walls, so that any preparation which will prevent these stains is very desirable and should be known to all architects. In Section 301 an English preparation, known as Duresco, is recommended for this purpose, but the author is informed that this material is not now carried in stock in this country.

A new preparation called *Antihydrine* is now made in this country, however, which appears to be an excellent article both for preventing the stains in plastering due to the mason work and for damp-proofing, and seems to have given excellent satisfaction.

Antihydrine is a high grade of ashphalt varnish, which can be applied cold to any porous surface without being absorbed by the material or becoming too thick in places. It is said to absolutely prevent the passage of moisture, which is generally admitted to be the agent which produces the stains in the plastering.

To prevent the staining of plastering it should be applied with a brush directly to the inside surface of the mason work, whether the latter be brick, stone or fireproof tiling. But one coat is required.

About twenty-four hours after the Antihydrine is applied, and while it is still soft, the plastering should be applied in the usual way. It has been found that plastering adheres to this coating equally as well as to brickwork, and that it dries much more quickly and evenly, and that decorating can be safely applied within a few days after the last coat of plaster is dry.

As the Antihydrine absolutely prevents the passage of moisture, furring the walls can be safely omitted, thereby effecting a saving in cost and in the thickness of the walls, and also, it is claimed, in the time required for drying the plastering.

Mr. Louis De Coppet Berg, of Cady, Berg & See, architects, states that his firm now omits furrings entirely, covering the wall instead with Antihydrine, and that they also cover all fireproof surfaces of partitions, ceilings, etc., with this material before plastering.

It has also been found to be an excellent base for whitewash, the second coat drying out perfectly white and free from stains.

When used under whitewash, however, the Antihydrine should be allowed to harden thoroughly before applying the whitewash, and at least two coats of the latter should be applied.

Antihydrine is also recommended for coating the built-in surfaces of limestone and marble, as it prevents the staining of the stone by the mortar. When this material is used common mortar may be used for laying the backing.

The manufacturers also state that they have found this preparation an excellent material for priming the outside of brick walls that are to be painted, as it takes the paint perfectly, and two coats of paint over one coat of Antihydrine makes a perfect job that will not peel or crack off.

The material is quite inexpensive.

Mr. Berg states that plastering that has already become stained cannot be improved by applying Antihydrine to its surface, it being necessary to apply the Antihydrine to the wall *before* plastering.

THE ROEBLING FIREPROOF FLOOR.

Additional Data Relative to Weight and Strength.— On page 290 is given the actual weight of various systems of fireproof floor construction when built between 12-inch beams. The concrete used in the Roebling floor in this test had broken stone aggregate. In nearly all buildings where this construction is used, however, the concrete is made of cement, sand and steam ashes or cinders, which greatly decreases the weight. The following table gives the average weight per square foot for floors constructed of concrete mixed in the proportion of 1 part Portland cement, 2 of sand and 5 of cinders, the weights being based upon results obtained by weighing the materials taken from sections of 12 and 15-inch levels two months old and perfectly dry. Of course when first laid they will exceed these weights.

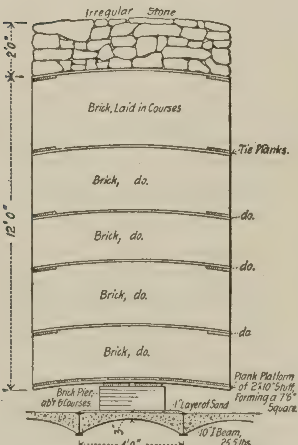


Fig. 250.

The table also gives the maximum spacing of floor beams for

different heights of arches, measured from under side of beam to top of arch.

WHEN CONCRETE IS TO BE LEVELED ABOVE UNDER SIDE OF FLOOR BEAMS TO A HEIGHT OF	MAXIMUM SPACING OF IRON FLOOR BEAMS (INDEPENDENT OF SIZE OF BEAMS) SHOULD NOT EXCEED	THICKNESS OF CROWN AT CENTRE OF ARCH.	WEIGHT PER SQUARE FOOT, INCLUDING ONLY CONCRETE AND WIRE.
8 inches.	4 feet 0 inches.	3 inches.	28 pounds.
9 "	4 " 6 "	3 "	30 "
10 "	5 " 0 "	3 "	33 "
12 "	6 " 0 "	3 "	39 "
15 "	7 " 6 "	3 "	53 "

In spans of over 5 feet allow $1\frac{1}{2}$ inches clear rise for each foot of span. The weights given are for concrete to level indicated in first column, with 3-inch crown, and for all wire construction, including arch wire for floors and lathing for ceiling. Add for plaster 8 to 10 pounds per square foot. Weight of structural iron and of wood or other finished floor must also be added for total dead load of floors.

All floor beams should be tied together at intervals of about eight times their depth, and should be framed level and flush on the under side where flat ceilings are desired.

The ceiling, when plastered, finishes about $1\frac{3}{4}$ inches below the lower flange of floor beams.

Test of Strength and Resistance to Fire.—As the great strength and fire-resisting qualities of concrete arches do not yet appear to be generally appreciated, the following report of a severe test of an arch built on the Roebling system is given for the benefit of any who may yet be skeptical on the subject, the description and illustration being taken from the *Engineering News* of February 4, 1897:

The floor arches shown in section in Fig. 250 were concreted on September 26, 1896, and on October 28 the fire test was made. The floor was loaded uniformly with 150 pounds to the square foot, and at 10 A. M. fires were lighted on the grates beneath the floor. The temperature on the under side of the floor was maintained at above 2,000° F. for three hours, and at 3 P. M. a powerful stream from a fire engine was thrown against the under side of the floor, which was at the time so hot as to glow.

After the floor cooled, on the following day, the load on the floor was increased to 600 pounds per square foot, still without signs of failure.

On December 11, 12 and 14 a section of one floor arch, 2 feet 6 inches long and 4 feet span, was isolated from the rest of the floor by cutting openings in the concrete from beam to beam on each side. Upon this was built a brick pier 2 feet 6

inches square and a foot high, and upon this pier was placed a platform of plank $7\frac{1}{2}$ feet square. This was then loaded with brick and stone, as shown in the figure until a weight of 40,000 pounds had accumulated and the pile became so top-heavy that further additions were deemed unsafe. The deflection of the arch under this load was 1 inch, and after the load was removed this was decreased to $\frac{5}{8}$ inch.

The concrete in this arch was composed of 1 part Aalborg Portland cement, 2 parts sand and 5 parts steam cinders.

THE EXPANDED METAL SYSTEMS OF FLOOR CONSTRUCTION.

The use of expanded metal in combination with concrete for floor construction has become so extensive that a description of the more common methods of using it may be considered as necessary to complete the subject of fireproof floor construction.

Two primary methods of construction are employed, the adoption of the one or the other depending upon the character of the building, the purpose for which it is to be used and the form of ceiling

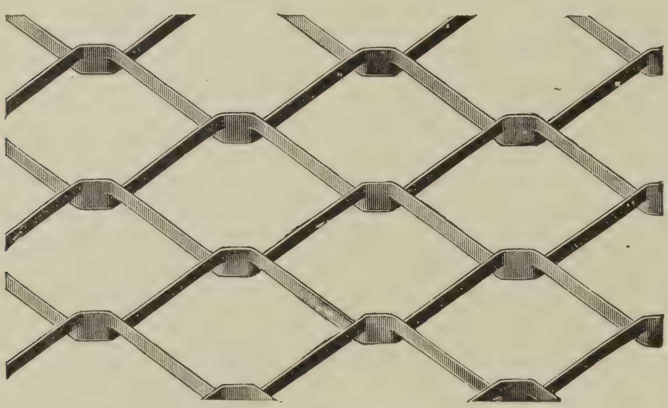


Fig. 25:.

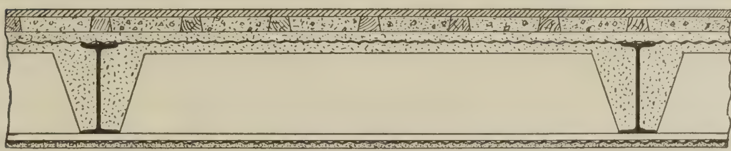
desired. In one of these methods, illustrated by Nos. 3, 5 and 8 Fig. 252, the floor is constructed as a composite slab, on the same principle as the Ransome floors, the expanded metal forming the tension member. In the other method the arch principle is emloyed, the expanded metal being used as a centre for the concrete.

The expanded metal used in floor construction is made by the same process as the expanded lath, but of heavier metal, usually from Nos. 10 to 16, and of either 3-inch or 4-inch mesh, the appearance of

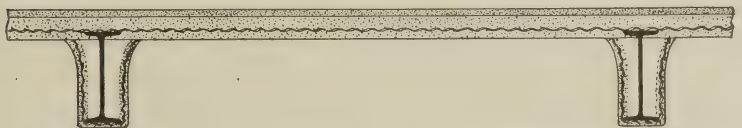
the floor material being as shown in Fig. 251, which is about one-quarter size.

Fig. 252 shows four styles of flooring which have been found best adapted to the usual requirements. The spans indicated are those which are usually the most economical, but they can be varied to suit the divisions of the building.

Systems 3 and 5 are most commonly used in office buildings,

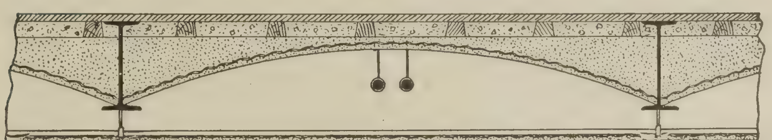


No. 3.—Span, 6 feet ; weight, 35 lbs. per sq. foot.



No. 5.—Span, about 8 feet ; weight. 30 lbs. per sq. foot.

No. 8.—Span, 4 feet ; weight, 35 lbs. per sq. foot.



No. 9.—Span, 6 feet ; weight, 45 lbs. per sq. foot.

Fig. 252.

hotels, etc. Where the rooms are uniformly arranged, with the partitions placed under one of the beams, system No. 5 may be used to advantage, and a considerable saving in the height of the building effected, as only about 5 inches of this height is taken up by the floor.

No. 8 is especially adapted to light floor loads such as are usually found in dwellings, apartment houses, etc., and where the beams do not need to be very heavy.

No. 9 is constructed by springing sheets of expanded metal be-

tween the floor beams and filling on top with concrete composed of Portland cement, sand and steam cinders. It is adapted to the heaviest loads and to spans of from 6 to 7 feet, or so that 8-foot sheets may be used for the arches.

The thickness of the floor slabs is usually about 3 inches, and of the arch at the crown from $2\frac{1}{2}$ to 3 inches. The weights given are exclusive of the beams and wood or tile flooring.

Repeated tests have demonstrated that either of the flat systems have abundant strength for the ordinary loads in office buildings, apartments, etc., and the arch system may be safely used for the heaviest warehouses. The tests have also shown that when overloaded, such floors do not fail suddenly, but quite gradually, thus giving warning of their dangerous condition.

TERRA BLANCA FIREPROOF TILING.

This is a fireproof material composed of silicates, alkalies, iron and gypsum, mixed with cinders and slag from blast furnaces.

It resembles in its appearance the various compositions of plaster that have been placed on the market, but the author believes that it is superior to them in its fire and water-resisting qualities.

The material is probably not surpassed even by porous terra cotta as a non-conductor of heat, and it does not appear to be greatly injured by intense heat, although, like all plastic materials, the surface softens by recalcining and also upon the application of water.

Terra Blanca is remarkably light in weight, and for this reason is well adapted for partitions and for ceilings under wooden joists. It is a non-conductor of sound; plastering dries on it very quickly, and it is inexpensive and easily put up. It is not capable of sustaining heavy weights, and should not be used for bearing partitions, but there are many places where, in the opinion of the author, it could be used to good advantage, especially in lessening the fire risks in wooden buildings and in making them more sound and vermin-proof. It is also used for fireproofing steel construction.

Although but very recently placed on the market, Terra Blanca has been used in several notable buildings in Chicago and in numerous buildings elsewhere.

It is moulded into slabs from 1 to 2 inches in thickness, $13\frac{1}{2}$ inches wide and 48 inches long; these slabs can be applied to wooden studding or floor beams, or to brick walls, by means of capped wire nails.

The partition slabs are made of the shape shown in Fig. 253 and 3, 4, 5 and 6 inches in thickness. These partition tile can be laid up

without mortar, small steel rods being used for holding them in place, as shown in Detail A, or they may be set in mortar and the rods omitted.

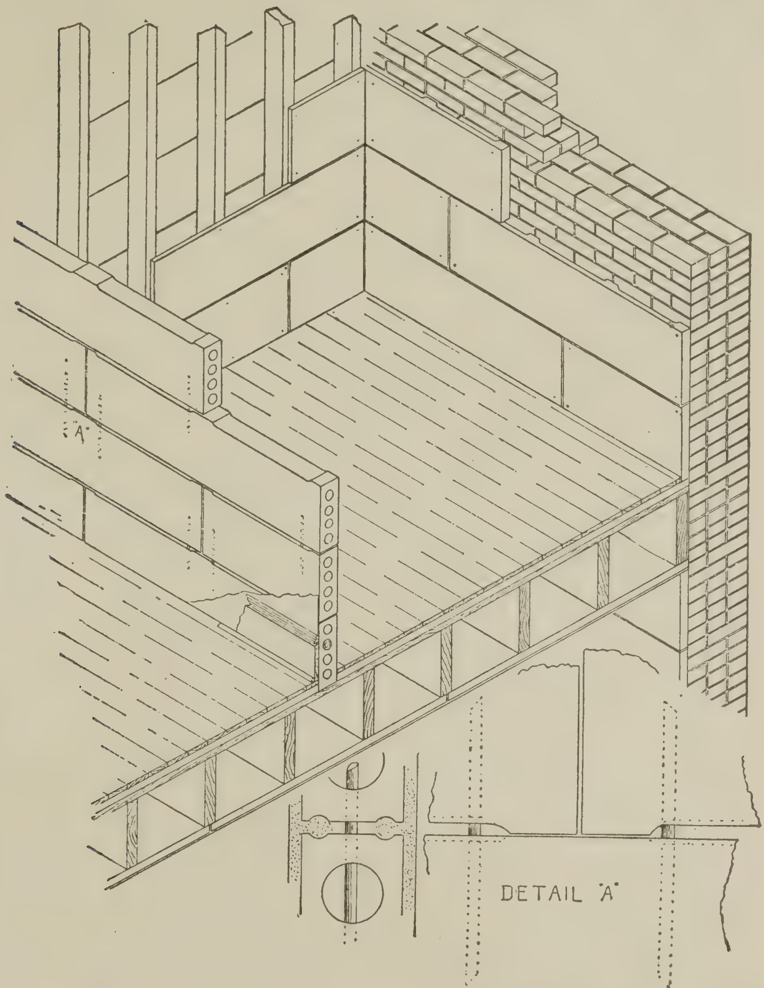


Fig. 253.

Nails can be driven into the tiles without breaking or chipping, and the tiles can also be readily cut with a saw. The manner of applying the tiles and slabs to wooden buildings is also shown in Fig. 253.

The weight per square foot of the 1-inch slabs is 4 pounds, of the 3-inch partition tile, 9 pounds; of the 4-inch, 11 pounds; of the 5 inch, 12 pounds, and of the 6-inch, 15 pounds. A partition of 4-inch tiles, with two light coats of plaster on each side, will not much exceed in weight an ordinary lath and plastered partition with 2x4-inch studding.

PELTON'S SYSTEM OF RELEASED WALL FACING.

During the past four years (1892-1896) Mr. John Cotter Pelton, architect, has developed and patented a system of released wall facing which has met with commendation from many prominent architects, and which the author believes to be sufficiently practicable as to interest all architects and students. The essential feature of this invention is the idea of supporting a costly facing of stone, marble or terra cotta from a wall of common masonry, or from a steel frame by means of metal anchors and brackets, which hold the facing away from the wall or frame and also permit of its being set after the supporting wall is completed. The general principle of construction is quite clearly indicated by Fig. 254.

The advantages claimed for this system are: First, economy of material in the facing; second, saving in time required to complete the building ready for occupancy; third, protection against the penetration of moisture; fourth, elimination of the bad effects of settlement in the walls and the staining of the facing from the backing; fifth, protection against exterior fire. Of these advantages the first and second will probably have the most influence in extending the use of the system, as they have a direct bearing upon the cost and financial returns of the building. The other advantages, however, are perhaps the most important from a constructive standpoint.

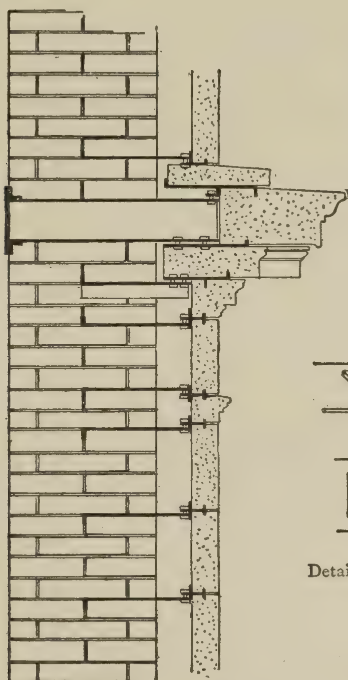
As the facing is treated merely as an external covering, principally for architectural effect, and has nothing to support, it can be made very thin, thus permitting the use of expensive materials, which, with the ordinary method of construction, would be prohibited on account of the cost.

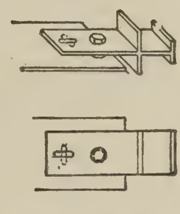
The anchors which support the facing being built into the supporting wall as it progresses, the facing can be applied after the roof is on and while the building is being finished on the inside, or even after the building is occupied. Hence a building faced with marble under this system could be completed ready for occupancy in about the same time that would be required if the walls were of plain brickwork, and ample time allowed for cutting and setting the facing, and

even for quarrying the stone. In fact, any unavoidable delays with the stonework, such as strikes, unfavorable weather, etc., need not delay the finishing of the interior of the building.

As a protection from dampness the advantage of this system is obvious, as a continuous air space is provided between the facing and the supporting wall, with only the metal anchors connecting the two.

The facing being applied after the supporting wall is completed, all settlement in the latter will have taken place before the ornamental work is set, thus avoiding the cracks which frequently occur in facings that are bonded into a brick backing. Of course any settlement in the foundations would affect the facing as well as the supporting wall. A facing supported in this way will also serve, while it endures, to protect the supporting wall from external fires, and should a portion or all of the facing be injured beyond repair, it can be removed and new pieces substituted. A facing of either marble





Detail of Anchors.

Fig. 254.

or limestone would probably protect the structural wall from serious damage from any ordinary fire; and even when the fire is inside the building this method of facing is likely to prove an advantage, as in such cases the flames generally destroy the stonework around the exterior doors and windows, and with a released facing the injured stones could be replaced if the structural wall was not weakened.

This system of construction has been adopted in a few buildings in California, of which the Public Library at Stockton, a building in the Renaissance style and designed by Mr. Pelton, is the most elaborate.

"This building stands on a corner and has exposed about 210 feet of frontage, the whole of which is of white marble on a light gray granite foundation wall 7 feet high. The structural walls are of brick, 24 inches in thickness, and the ashlar is $2\frac{1}{4}$ inches thick, with an air space of $2\frac{3}{4}$ inches. The whole of the work on this building, except the finishing coat of plaster and the interior woodwork, was completed before the marble for the facade was delivered upon the ground. The whole cost of the exterior marble work was less than $17,000, in which is included not less than $3,000 for carving and the cost of six monolithic columns 16 feet in height."

The anchors or carriers in this building were all set and adjusted by an engineer, so as to secure perfect alignment, and no difficulty appears to have been encountered in any portion of the work, the appearance of the building on completion being the same as if constructed in the ordinary way.

"At one time during the progress of the work there were men at work at not less than five different parts of the building and on eight different levels.

"Every stone sent to the staging as correct in size was set without trimming; in fact, fitting and trimming were not known upon the staging. The only cutting known to have been done in the work of setting was the small amount of channeling required for the carriers, and this work hardly occupied the time of one workman."

The shape and size of the carriers or anchors will necessarily depend a good deal upon the size and weight of the pieces to be supported. The shape of some of the carriers used in the Stockton Library is shown in Fig. 254. To insure the successful setting of the facing the carriers must be set with great exactness, and Mr. Pelton recommends that an engineer be employed to give both the horizontal and plumb lines.

The window frames should be set before the facing and the latter built around them.

As stated in the first paragraph, this system of construction has been patented by Mr. Pelton, and architects who wish to adopt it should consult with him in regard to royalty, details of the carriers, etc.

INDEX TO ADDITIONS.

[SECOND EDITION.]

INDEX.

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